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Reynolds Creek Watershed. Interim Report
No. 2, January 1, 1970-June 30, 1971
ARS-BLM Cooperative Studies

(U.S.) Agricultural Research Service, Boise, ID

Prepared for

Bureau of Land Management, Portland, OR

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ARS-BLM COOPERATIVE STUDIES

REYNOLDS CREEK WATERSHED

INTERIM REPORT, NO. 2

For Period January 1, 1970, to June 30, 1971

To

Portland Service Center
Bureau of Land Management
U. S. Department of the Interior
Portland, Oregon

From

Northwest Watershed Research Center
Soil and Water Conservation Research Division
Agricultural Research Service
U. S. Department of Agriculture
Boise, Idaho

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As stated in Interim Report No. 1 (March, 1970), the purpose of the ARS-BLM cooperative studies is to accelerate research on precipitation-runoff and sedimentation characteristics of watershed areas with specific soil-vegetation characteristics, together with quantifying the effects of certain management and treatment practices applied thereto. These joint efforts, during the reporting period, have been concerned with the water balance and sediment production on sagebrush rangelands as specified in the Agreement Renewal for FY 1971.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

ARS-BLM COOPERATIVE STUDIES

REYNOLDS CREEK WATERSHED

INTRODUCTION

As stated in Interim Report No. 1 (March, 1970), the purpose of the ARS-BLM cooperative studies is to accelerate research on precipitation-runoff and sedimentation characteristics of watershed areas with specific soil-vegetation characteristics, together with quantifying the effects of certain management and treatment practices applied thereto. These joint efforts, during the reporting period, have been concerned with the water balance and sediment production on sagebrush rangelands as specified in the Agreement Renewal for FY 1971.

Research was conducted in the Reynolds Creek Experimental Watershed, as documented in the 1970 Annual Report of the Northwest Watershed Research Center (attached as supplement) with emphasis on infiltration (Res. Outline, Ida-Bo-105.6), two-dimensional flow systems (Res. Outline, Ida-Bo-105.5), evapotranspiration (Res. Outline, Ida-Bo-106.1), sedimentation (Res. Outline Ida-Bo-107.1), and cover-soil conditions for different levels of management (Res. Outline, Ida-Bo-106.1). The latter Research Outline entitled: "Evaluation of Cover Production, Herbage Yield, and Soil Conditions for Different Levels of Vegetation Management," was formalized during the reporting

period. Progress in the development of study sites and a summarization of research investigations are included in this Report.

STUDY SITES

Locations of the eight study sites, developed to study the interrelationships of cover, herbage yield, soil conditions, infiltration, evapotranspiration, and sediment production under different levels of vegetation management are shown in Figure 1. Site information was included in Table 1 of Interim Report No. 1 (1970). The Nettleton site was selected, fenced, and partially instrumented during the past year. The development of a study site on granitic soils was postponed until next year.

Fencing for livestock exclosure or control was completed at all active sites prior to the 1971 grazing season and close-mesh fencing to exclude rabbits was installed at the Lakebed Flats site. Photographs of three of the eight study sites, Lakebed Flats, Nancy's Gulch, and East Reynolds Mountain, are included as Figures 2, 3, and 4, respectively.

INSTRUMENTATION

Runoff and Sediment

Instrumentation for runoff and sediment measurement on 2 to 3-acre micro-watersheds was installed at the Lakebed Flats and Nancy's Gulch sparse cover sites. Figure 5 is a sketch of a typical

period. Progress in the development of [illegible] and [illegible] of research investigations are [illegible].

STUDY SITES

Locations of the eight study sites [illegible] interrelationships of [illegible] [illegible]

[illegible]

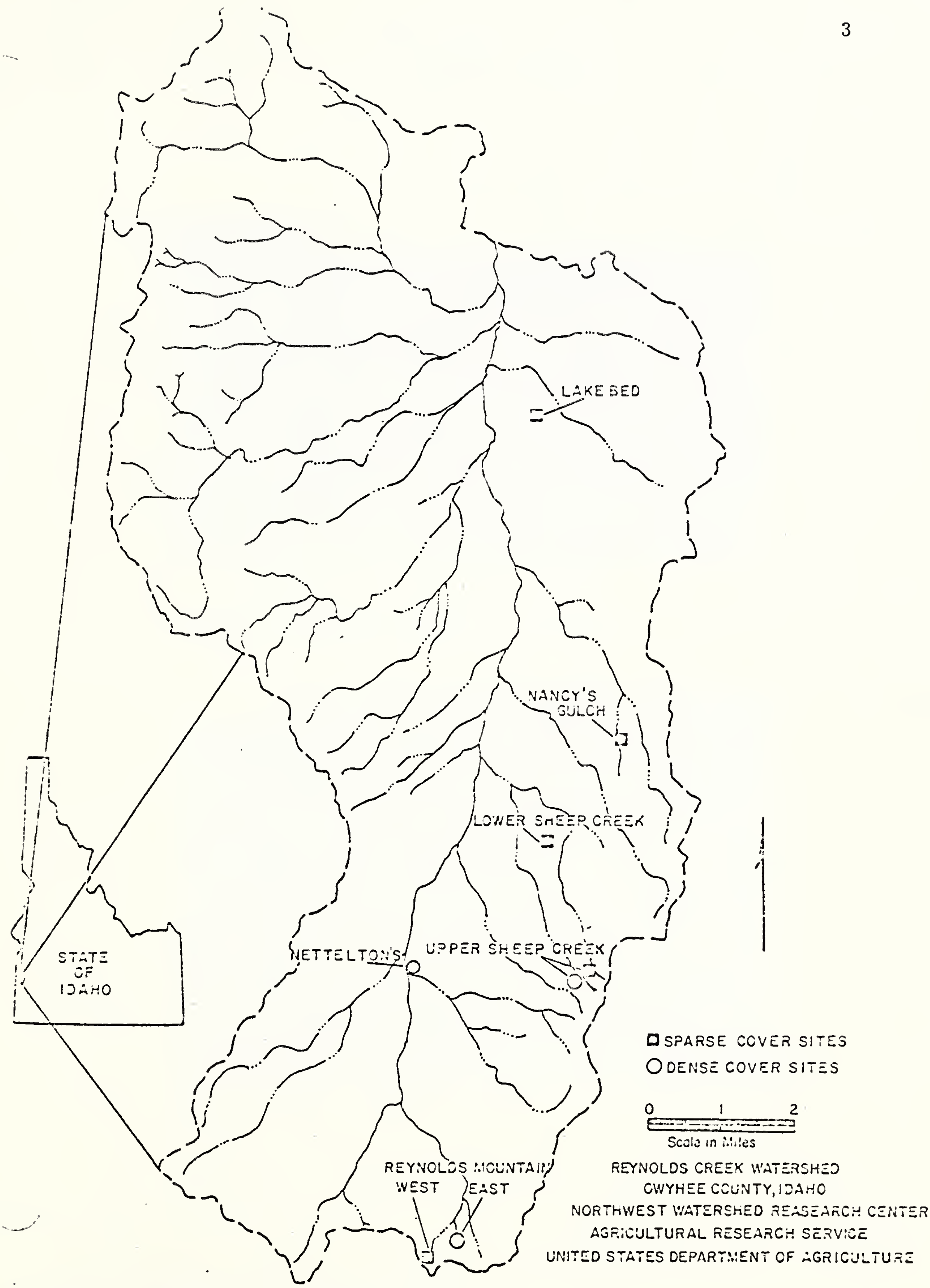

Figure 1. Location of experimental sites.

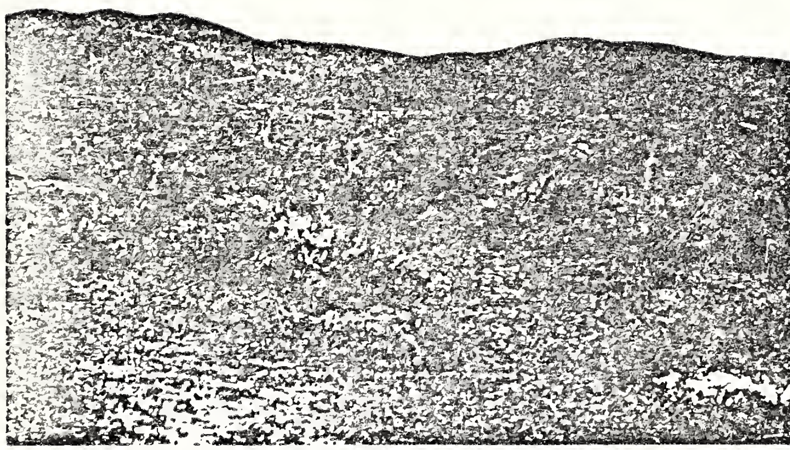

FIGURE 2. Flats Study Site.

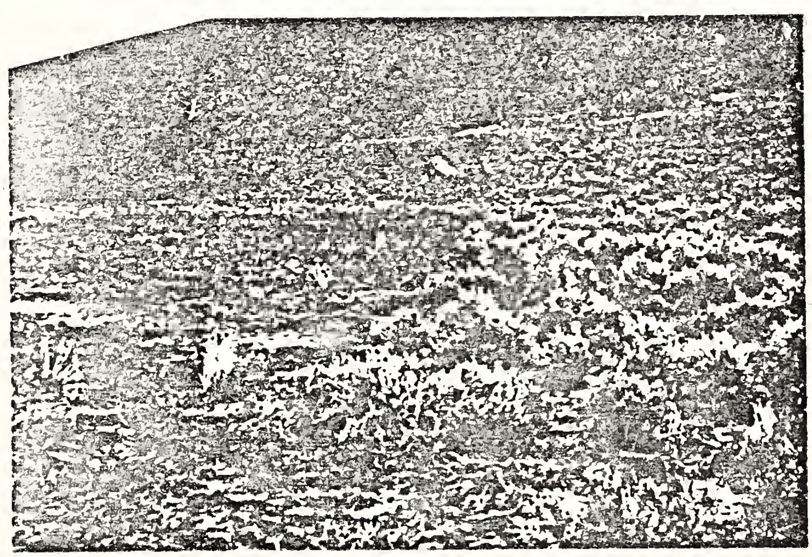

FIGURE 3. Nancy's Gulch Study Site.

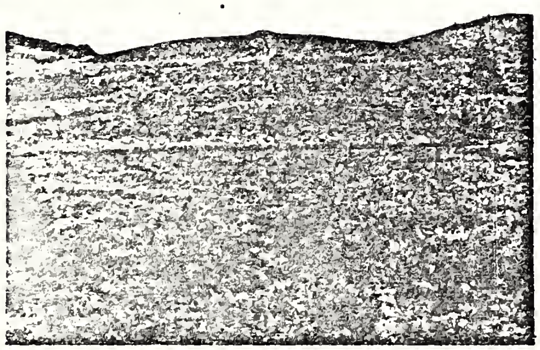

FIGURE 4. Reynolds Mountain (East) Study Site.

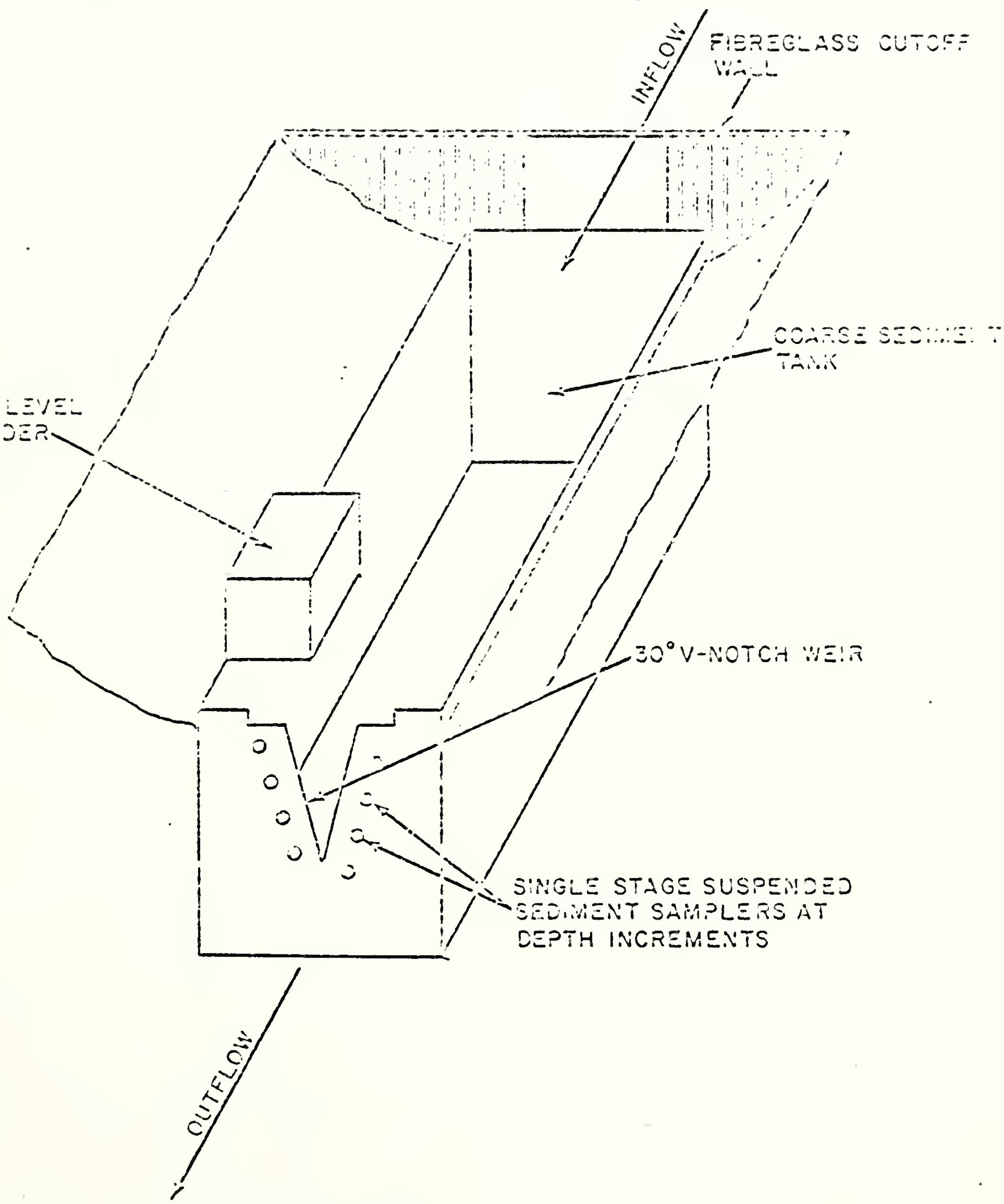

FIGURE 5. Sketch of a Typical Runoff-Sediment Installation for Micro-Watersheds of 1 to 3 Acres.

runoff-sediment installation which includes: (1) a fiberglass cutoff wall extending to backhoe excavating depth, (2) a catchment tank for coarse sediments, (3) a 30-degree V-notch weir and water-level recorder to measure runoff, and (4) a series of single-stage suspended sediment samplers with intakes at regular depth intervals to sample sediment concentrations at varying flow rates. Also, a 14-ft. by 72-ft. grazed, sparse vegetative cover plot at the Nancy site was instrumented with borders, a collector, tanks, a water-level recorder and splitter (Figure 6) to measure runoff and sediment production during storm events. Similar installations will be installed at the four other sites with sparse vegetative cover. Additional runoff and sedimentation facilities at Upper Sheep Creek and Reynolds Mountain were described in Interim Report No. 1 (1970).

Soils Moisture and Vegetation

Installation of access tubes for measurement of soil moisture using both the gamma and neutron systems was completed at all sites except the sparse vegetation study site at Upper Sheep Creek.

Round portable exclosures seven feet in diameter were constructed to protect herbage yield plots from grazing while plants were maturing. Triangular exclosures similar to steel gate panels were also constructed for the same use on dense vegetation sites.

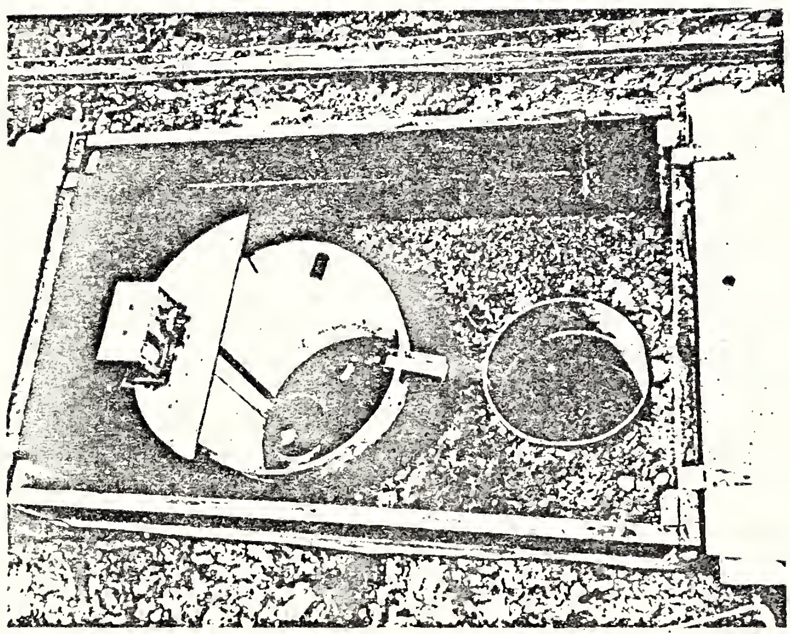

FIGURE 6. Plot Collector, Tanks, Recorder and Splitter for Runoff and Sediment Measurement.

Instrumentation for measurement of temperature, relative humidity, and wind were installed at Nancy's Gulch and Upper Sheep Creek. Such instrumentation was already in operation at Lower Sheep Creek and Reynolds Mountain.

INVESTIGATIONS

Infiltration and Flow in Porous Media[1/]

Studies concerned with infiltration and flow in porous media are discussed in detail in the 1970 Annual Report, Research Outlines Ida-Bo-105.5 and Ida-Bo-105.6. A summarization of these studies is presented in the following paragraphs:

The accuracy and utility of computer solutions of the partial differential equations that describe unsteady-state, axisymmetric infiltration were evaluated for use as a prediction model. Laboratory tests were conducted on large soil-cores by using a rainfall simulator-gamma-probe-infiltrometer. This instrumentation was discussed in Interim Report No. 1 (1970).

A mathematical model describing transient flow of water from circular infiltrometers was formulated and analysis of preliminary numerical solutions was accomplished by Jeppson (1).[2/] Pertinent

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1/ Research on infiltration and flow in porous media was conducted cooperatively with Utah State University and Oregon State University.

2/ Numerals in parentheses refer to publications, page 23.

features that describe the flow characteristics obtained from 34 solutions for varying initial conditions and for 12 soil types were summarized in tables and figures. Relationships between depth of moisture penetration and the following characteristics were developed: (1) lateral movement of the wetting front, (2) rate of moisture application, and (3) initial soil-moisture tension.

In a companion report, Jeppson (3) described the determination of hydraulic conductivity-capillary pressure relationships from saturation-capillary pressure data for soils. The Burdine Theory was used to obtain relative permeability from the pressure-saturation data. The report describes a computer program used to evaluate Burdine Integrals and describes input to and output from the program.

Solution to transient, vertical, moisture movement based upon saturation-capillary pressure data and a modified Burdine Theory was described by Jeppson (4) in a later report. This formulation and solution method is consistent with the solution method developed earlier (1, 2, 3) for three-dimensional, axisymmetric movement of water applied at the ground surface within a circular infiltrometer. This formulation was deemed necessary, so that comparisons of the solution results from the two different cases would indicate quantitative effects on the flow pattern of the component of radial, moisture movement.

Vertical moisture-movement solutions were obtained (4) for several initial moisture contents and for several application rates for a sample of disturbed soil taken from the summit area of the Reynolds Creek Experimental Watershed. Saturation-capillary pressure data for this soil were obtained in the laboratory. In addition, laboratory measurements of the hydraulic conductivity corresponding to a number of capillary pressures were obtained. Using the saturation-capillary pressure data in the Burdine Equations for evaluating hydraulic conductivity gave good agreement with the laboratory measurements of hydraulic conductivity.

In a later report that is not included in the Annual Report, Wei and Jeppson (5) obtained solutions to the problem of steady-state infiltration of moisture that moves through partially saturated, homogeneous soils toward a water table from a circular area of application. Solution techniques were formulated, and solution results presented. The solutions indicate that significant radial movement of moisture (spreading effect) occurs and causes higher infiltration rates at the edge of the horizontal source circle than near the center. The infiltration rate is closely related to various soil parameters that characterize the hydraulic properties of soils. Also presented are several distributions of the relative permeability or effective saturation on the surface, along the axis of symmetry, and on the plane

including the axis of symmetry. In addition, the report indicates how the distributions of relative permeability or of effective saturation are related to the soil parameters.

During the spring of 1971, saturation-capillary pressure data were obtained from four 32-inch diameter, undisturbed soil cores. These cores were taken from different locations on the Reynolds Creek Experimental Watershed and included different soil types. Small cores, 2-inch in diameter, were extracted from the large cores for obtaining conductivity-pressure data in the laboratory. In addition, a mathematical model of transient, vertical moisture movement through layered soils was essentially completed.

In another study the adequacy of a numerical solution of the steady-state, two-dimensional flow system resulting from infiltration of water from melting snow was tested. Jeppson and Schreiber (6) described the mathematical model, and Schreiber, et al. (7) evaluated the model by field data obtained from a northern-slope section of the Upper Sheep Creek Watershed.

The model (6) provides for soil heterogeneity, soil anisotropy, and partially saturated-saturated flow regions. A representative solution, illustrates the capability and flexibility of the model.

Field measurements obtained by Schreiber, et al. (7) during 1970 included soil moisture, soil capillary pressure, piezometric fluctuations, precipitation, snowpack volume, snowpack water content,

snowmelt, and streamflow. Soil properties were determined in the laboratory.

Mathematical solutions and laboratory data indicated that saturated hydraulic conductivity characteristically varies with distance up slope from the stream channel. Other parameter variations, such as anisotropy, could be specified to bring solution results in agreement with observed conditions.

A different solution technique, Kirchhoff Transformation, for the solution of transient flow of water from a circular infiltrometer was described in a supplemental report by Jeppson (2). It was suggested that the numerical solution might be improved for situations containing regions of nearly saturated flow by means of the Kirchhoff Transformation. Example solution results are presented in the report.

Evapotranspiration[3/]

Studies concerned with evapotranspiration from sagebrush range sites are summarized in the 1970 Annual Report (Res. Outline, Ida-Bo-106.1.) Further information on the studies was reported by Belt(3).

Estimates of evapotranspiration from sagebrush rangelands by the Bowen ratio method and by energy balance-combination equations were made, using data obtained by micrometeorological instrumentation during the summers of 1969 and 1970. The Bowen ratio estimates were found to be smaller than those obtained by other methods.

3/ Research on evapotranspiration from sagebrush rangelands was conducted cooperatively with the University of Idaho.

The apparent difficulty in using the Bowen ratio method in semi-arid environments lies in the assumption of equality in the transfer coefficients of heat and water vapor and in obtaining reliable measurements of very small vapor pressure gradients. The energy balance-combination equation for computing evapotranspiration that requires humidity data in addition to surface temperature and radiation required in the basic energy balance equation is not applicable since the computations were found to be redundant.

Sufficient data have been obtained to evaluate the inequality of the transfer coefficients of heat-vapor and momentum. This step will make it possible to obtain independent estimates of evapotranspiration for testing a proposed energy balance equation, based on the resistance concept, to compute evapotranspiration from sparsely vegetated rangelands.

Runoff and Sedimentation

During the 1969-70 water year the only important runoff producing events occurred during the January 21-27, 1970, storm and the May-June snowmelt period. January precipitation varied from 2.96 inches at 3915 feet elevation to 9.52 inches at 6800 feet. Although the January precipitation reached near record amounts, only minor flooding occurred and the high elevation snow absorbed most of the rain. Also, sediment production from the January runoff was low at the Reynolds Mountain and Upper Sheep Creek sites.

The snowmelt season was somewhat later than normal and melt runoff from higher elevations occurred mainly in late May and early June. Snowmelt runoff and sediment production were about normal. Further details are contained in the 1970 Annual Report (Res. Outline Ida-Bo-107.1). Processing and compiling of runoff and sediment data for the 1970-71 water year are scheduled for completion in December 1971 and will show above normal winter precipitation and snow accumulation.

Soil Moisture and Vegetation

Duplicate micro-plots of 3 ft. by 3 ft. were established at all study sites for each type of vegetation treatment. Initial surveys of these plots were completed regarding identification of species of grasses and forbs, and the measurement of the basal area of grasses present.

These plots were also charted and photographed. Any fluctuations in either species composition or basal area of grass clumps caused by treatments imposed will be compared with this initial

information. Figure 7 shows one of the microplots on the brush-removed treatment at Upper Sheep Creek. Clippings were also taken from all sites for measurement of herbage yield.

Soil moisture measurements were obtained at three of the study sites: Lakebed Flats, Nancy's Gulch, and Upper Sheep Creek, during the period of this report. The neutron depth gauge was used for measurements below six inches. Use of the gamma density probe was initiated in 1971 for the purpose of following moisture change in the 0-6 inch zone. Figure 8 shows a scaler for gamma measurements being used at Upper Sheep Creek while Figure 9 shows the scintillation probe of the gamma system.

Studies were initiated in 1969 to evaluate the effects of various brush treatments on herbage yield. This initial study was incorporated into Res. Outline, Ida-Bo-105.4. Results from the study in 1970 are reported in the 1970 Annual Report, page 7-7. Figures 10 and 11 show the sites from which brush was removed and sprayed, respectively, with all grazing animals excluded. Figure 12 shows the grazed treatment.

Cover transects were recorded for all sites and each site was assigned an erosion condition class derived from the BLM Soil Surface Factor rating sheet. Cover measurements and erosion condition are given in Table 1.

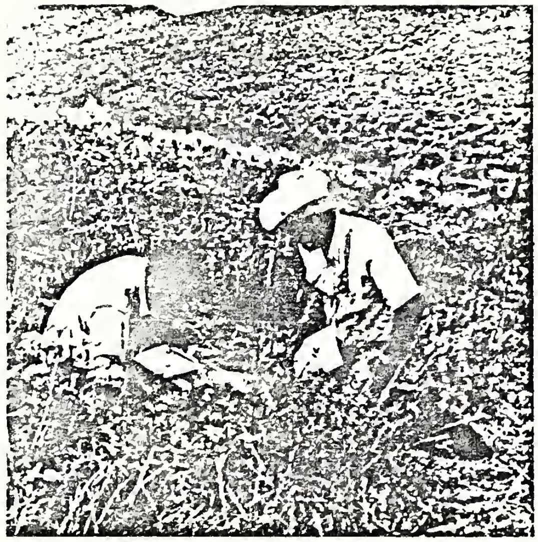

FIGURE 7. Microplot, 3 ft. by 3 ft. for Charting Vegetation Changes (Upper Sheep Creek)

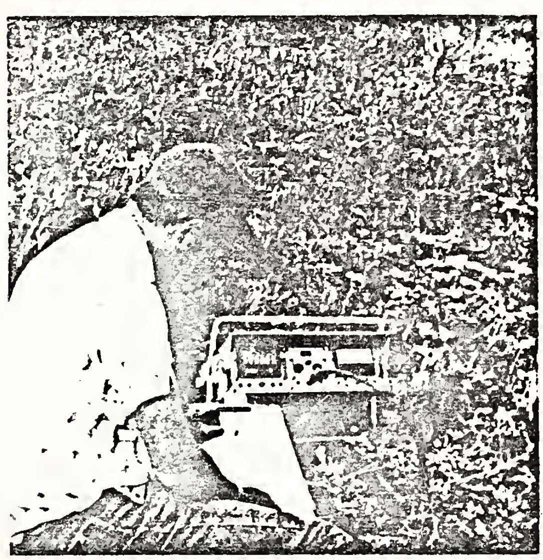

FIGURE 8. Scaler for Gamma System Used to Determine Soil Moisture.

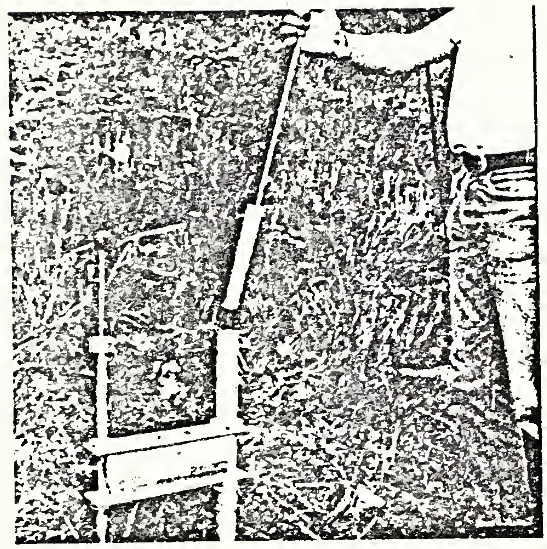

FIGURE 9. Scintillation Probe and Standards for Gamma System.

FIGURE 10. Brush Removed Treatment, Upper Sheep Creek.

FIGURE 11. Sprayed Plot (2,4,5-T)
Upper Sheep Creek.

FIGURE 12. Grazed Site
Upper Sheep Creek.

TABLE 1: COVER MEASUREMENTS AND EROSION CONDITION ON STUDY SITES

Site and Treatment	Vegetation %	Litter %	Small Rock %	Large Rock %	Bare Ground %	Erosion Condition (Class)
Lakebed Flats						
Grazed	40.6	24.9	4.7	0.0	29.9	Slight
Exclosure - Not grazed	39.4	25.4	4.9	0.0	30.3	Stable
Nancy's Gulch						
Grazed	38.6	27.4	12.7	0.1	21.1	Slight
Exclosure - No brush treatment	43.4	25.1	14.3	0.7	16.4	Slight
Exclosure - Sprayed	41.3	27.1	13.1	0.6	17.9	Slight
Exclosure - Sage removed	28.4	30.9	12.9	1.3	26.6	
Lower Sheep Creek						
Grazed	48.4	19.1	24.7	0.4	7.3	Moderate
Exclosure - Not grazed	55.6	18.4	18.3	0.6	7.1	Moderate
Upper Sheep Creek (North)						
Grazed	40.7	15.1	23.4	1.9	18.9	Moderate
Exclosure - Not grazed	52.0	15.6	19.1	1.3	12.0	Moderate
Reynolds Mountain (West)						
Grazed	50.6	11.3	33.0	0.0	5.1	Stable
Exclosure - Not grazed	48.4	11.1	35.8	0.3	4.3	Stable
Upper Sheep Creek (South)						
Grazed	78.9	19.8	0.0	0.0	1.3	Stable
Exclosure - No brush treatment	87.6	12.0	0.0	0.0	0.4	Stable
Exclosure - Sprayed	89.4	9.6	0.0	0.0	1.0	Stable
Exclosure - Sage removed	89.4	8.6	0.0	0.0	2.0	Stable
Reynolds Mountain (East)						
Grazed	86.3	12.4	0.1	0.0	1.1	Stable
Exclosure - No brush treatment	83.7	13.9	0.1	0.0	2.3	Stable
Exclosure - Sprayed	83.6	14.7	0.4	0.0	1.3	Stable
Exclosure - Sage removed	57.0	38.4	0.4	0.1	4.0	Stable
Nettletons						
Grazed	68.1	25.0	2.3	0.3	4.3	Stab'
Exclosure - Not grazed	74.4	20.3	1.4	0.3	3.3	Stable

SUMMARY

Data collection was initiated on eight special study sites (Figure 1, page 3). These sites were developed to study the interrelationship of cover, herbage yield, soil condition, infiltration, evapotranspiration, and sediment production under different treatments. Tabulations of cover measurements and erosion condition classes for separate treatments are given in Table 1, page 20.

Instrumentation yet to be completed on the study sites include soil moisture access tubes on Upper Sheep Creek (North) and permanent runoff-sediment measurement plots on four sparsely vegetated sites. This work is scheduled for completion during FY 1972 with one additional study site to be installed on granitic soils.

The cooperative investigations of a two-dimensional, steady-state watershed flow system was essentially completed and reported in publications 6 and 7. Other investigations concerned with infiltration led to the development of a mathematical model to describe the three-dimensional axisymmetric flow of water from an infiltrometer through partially saturated soil and a model for calculating the one-dimensional, vertical movement of water in soil. These models and solution techniques are reported in publications 1, 2, 3, 4, and 5. Laboratory and field data have been obtained to test the applicability of these models.

PUBLICATIONS

1. Jeppson, R.W. 1970. Transient flow of water from infiltrometers--formulation of mathematical model and preliminary numerical solutions and analyses of results. Project report PRWG-59c-2. Utah Water Research Laboratory, Utah State University, Logan.

2. Jeppson, R.W. 1970. Formulation and solution of transient flow of water from an infiltrometer using the Kirchhoff Transformation. Project report PRWG-59c-3. Utah Water Research Laboratory, Utah State University, Logan.

3. Jeppson, R.W. 1970. Determination of hydraulic conductivity-capillary pressure relationship from saturation-capillary pressure data from soils. Project report PRWG-59c-4. Utah Water Research Laboratory, Utah State University, Logan.

4. Jeppson, R.W. 1970. Solution to transient vertical moisture movement based upon saturation-capillary pressure data and a modified Burdine Theory. Project report PRWG-59c-5. Utah Water Research Laboratory, Utah State University, Logan.

5. Wei, C-Y., and Jeppson, R.W. 1971. Finite difference solutions of axisymmetric infiltration through partially saturated porous media. Project report PRWG-59c-6. Utah Water Research Laboratory, Utah State University, Logan.

6. Jeppson, R.W. and Schreiber, D.L. 1971. Solution of a two-dimensional, steady-state watershed flow system: Part I. Description of mathematical model. A portion of Paper No. 71-255 presented at the Annual Meeting of the American Society of Agricultural Engineers at Washington State University, Pullman. Submitted in July 1971 for possible publication in the Transactions of the ASAE.

7. Schreiber, D.L., Jeppson, R.W., Stephenson, G.R., Johnson, C.W., Cox, L.M., and Schumaker, G.A. 1971. Solution of a two-dimensional, steady-state watershed flow system: Part II. Evaluation by field data. A portion of Paper No. 71-255 presented at the Annual Meeting of the American Society of Agricultural Engineers at Washington State University, Pullman. Submitted in July 1971 for possible publication in the Transactions of the ASAE.

8. Belt, G.H. 1970. Spring evapotranspiration from low sagebrush range in southern Idaho. Research Project Technical Report, Project A-014-Ida. Water Resources Research Institute, University of Idaho, Moscow, Idaho (October).

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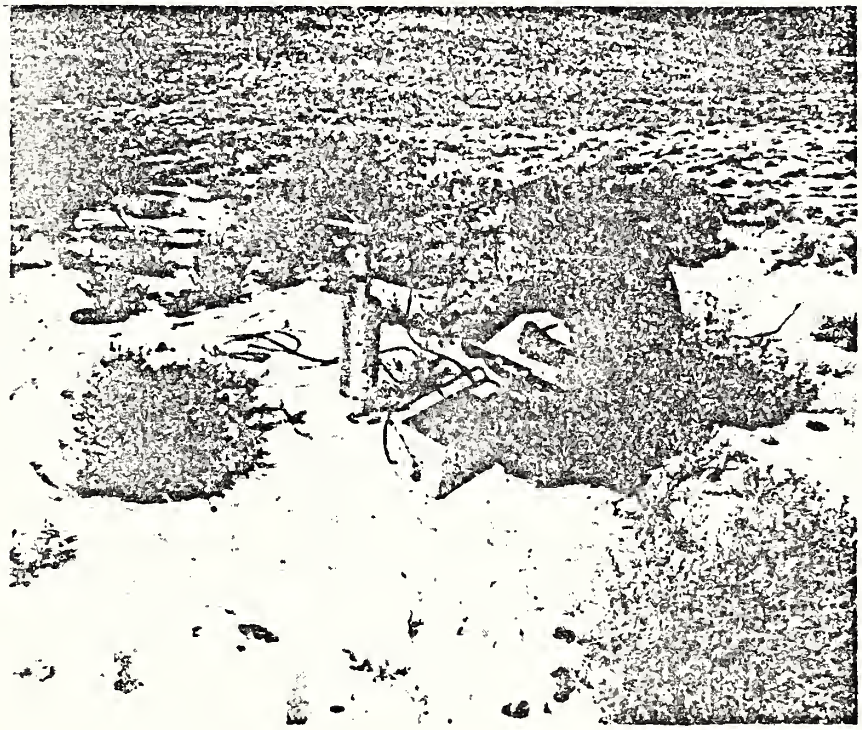
SUPPLEMENT

ARS-BLM COOPERATIVE STUDIES - REYNOLDS CREEK WATERSHED

INTERIM REPORT NO. 2

ANNUAL REPORT FOR THE YEAR 1970



NORTHWEST WATERSHED RESEARCH CENTER

United States Department of Agriculture
Agricultural Research Service
Soil and Water Conservation Research Division
Northwest Branch

BOISE, IDAHO

In cooperation with the Experiment Stations of Idaho, Oregon and Washington

TABLE OF CONTENTS

PREFACE

STATEMENT OF MISSION

Congress, in 1960, established the Northwest Watershed Research Center to gain basic information on runoff characteristics, including water yield, from plateau and foothill grazing areas of the Northwest and basic information on runoff and sediment problems of the Northwest wheat-producing areas.

The research mission is to gain a better understanding of the role of the land and the influences of vegetation, climate, and land management on the movement of water and sediment.

Objectives of the research program concerning the hydrologic performance of range and agricultural lands are:

1. To measure water and sediment yields, evapotranspiration, changes in storage of soil moisture and ground water, precipitation and other climatic variables on selected study areas at representative locations in the Northwest.

2. To define the influence of soil, vegetation, climate, geology, and land management on the disposition of precipitation and on sediment yield for the study areas.

3. To develop a hydrologic model for the prediction of water and sediment yields from range and agricultural lands in terms of readily obtainable climatological and physical data for different management levels.

Research is conducted in cooperation with the Experiment Stations of Idaho, Oregon, and Washington, and with the Owyhee Soil Conservation District, the Soil Conservation Service, and the Bureau of Land Management. Research findings are documented in the technical literature, and hydrologic data are released following evaluation for use by other groups or individuals.

Annual Report for the Year 1970

INTRODUCTORY MATERIAL

This annual report is a combined effort of the professional, non-professional, and clerical staff of the Northwest Watershed Research Center, Boise, Idaho.

A. STATION OPERATION

1. Personnel: All personnel employed during the reporting year are included in the following list, except for temporary employees on short-term appointments.

Professional

Name	Title	Research Responsibilities
W. R. Hamon	Research Hydraulic Engineer (RIL and Center Director)	1. Hydrologic models. 2. Precipitation, infiltration, and evapotranspiration. 3. Center administration and technical supervision.
C. W. Johnson	Research Hydraulic Engineer	1. Runoff investigations. 2. Sedimentation. 3. Weir construction.
L. M. Cox	Research Soil Scientist	1. Snowmelt studies. 2. Evapotranspiration studies.
D. L. Schreiber	Research Hydraulic Engineer	1. Surface runoff, infiltration, and ground water. 2. Hydrologic models. 3. Sedimentation.
G. A. Schumaker	Research Soil Scientist Starting 7-26-70	1. Soil and vegetation studies. 2. Vegetative response to management and treatment. 3. Soil moisture.
G. R. Stephenson	Geologist	1. Hydrogeologic investigations. 2. Geomorphology studies. 3. Geochemistry of ground water.

Professional (Continued)

Name	Title	Research Responsibilities
F. H. Smith	Botanist LWOP attending Colorado State University	1. Vegetation influences. 2. Precipitation characteristics. 3. Snow deposition.
E. C. Richardson	Research Agronomist To 3-21-70	1. Erosion investigations. 2. Evaluation of vegetative response to management and treatment.
J. M. Clark	Mathematician To 9-6-70	1. Data processing. 2. Computer programming. 3. Statistical analysis.

Clerical

Name	Title	Duties
N. C. Cotton	Clerk-Stenographer	1. Secretarial. 2. Bookkeeping. 3. Personnel.
J. L. Hall	Clerk-Stenographer	1. Stenography 2. Filing and travel. 3. Library.
T. D. McCurdy	Clerk-Stenographer	1. Stenography 2. Procurement. 3. Receptionist.

Subprofessional

General Schedule

Name	Title	Duties
D. L. Coon	Engineering Technician	1. Data collection and reduction.
C. D. Engelbert	Engineering Technician	1. Runoff data collection. 2. Sediment sampling.
G. L. Marcum	Electronic Technician	1. Electronics. 2. Instrumentation.

Subprofessional (Continued)

General Schedule

Name	Title	Duties
D. C. Robertson	Engineering Technician	1. Data collection and reduction. 2. Instrumentation.
J. F. Zuzel	Engineering Technician	1. Hydrogeological data collection and analysis 2. Data procurement scheduling. 3. Drafting.
M. D. Burgess	Electronic Technician To 10-3-70	Instrumentation.

Wage Grade

Name	Title	Duties
M. I. Gasser	Soil Research Helper To 9-26-70	Data reduction.
R. F. Hermann	Carpenter Leader	Construction.
R. N. Hoagland	Automotive Mechanic	Automotive repairs.
Lee Perkins	Maintenance Worker	1. Field instrumentation. 2. Maintenance.
K. W. Trautman	Engineering Equipment Operator	1. Equipment maintenance. 2. Road construction.
C. F. Ward	Carpenter	Construction.

Other

In addition to the foregoing, a number of temporary employees were used to the extent of 502 man-days in construction, 152 man-days in instrumentation, 380 man-days in data acquisition and processing, and 260 man-days clerical, or a total of 1294 man-days.

2. Facilities

The research offices are located in a leased building at 306 N. 5th Street, Boise, Idaho. Facilities located at Gowen Field (Boise Airport) consist of a shop housed in a quonset building and a soils, geology, and instrument laboratory housed in a prefabricated steel building. The Reynolds Creek Experimental Watershed field headquarters is located in the watershed at Reynolds, Idaho, 50 miles southwest of Boise, and consists of a quonset building and storage sheds on 3 acres of leased land.

3. Instrumentation[1/]

A tabular summary of instrumentation is found in Table 1, (p. 1-5). Location maps are shown in Figures 1 and 2 for Reynolds Creek Watershed and Rabbit Creek Watershed, respectively.

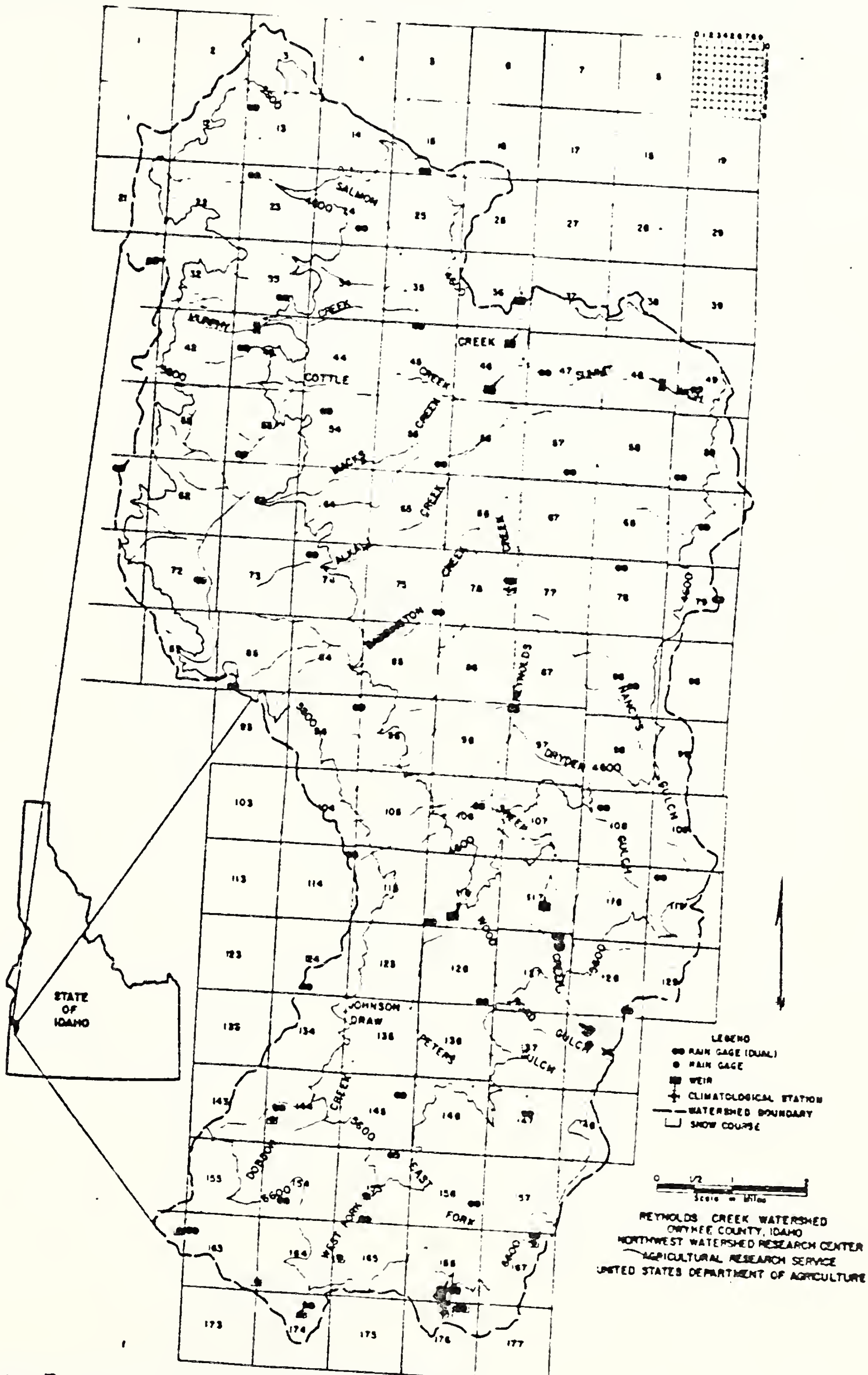
Instrumentation additions during the reporting year include: (1) installation of neutron and gamma probe access tubes at Reynolds Mountain Watersheds, Sheep Creek Watersheds, Nancy Gulch study area and Lakebed Flats study area; (2) spring development and installation of water measuring devices at Reynolds Mountain West Watershed and near the Summit Watershed; (3) installation of a Universal Surface Precipitation Gage, snow pillows, and precipitation gages in the drainage basin of the West Fork of Reynolds Creek; (4) an improved solarimeter at the Lower Sheep Creek Weather Station; (5) gravity suspended sediment samplers at Moscow, Idaho (Thompson Watershed) and the Summit Watershed tributary to Reynolds Creek; (6) a runoff-sediment plot and tanks at the Nancy Gulch study area; and (7) an infiltrometer rainfall simulator test facility for undisturbed soil cores at the Reynolds Field Headquarters. Also, several study sites were fenced.

1/ Locations are found by use of the Federal system of land divisions where each section in the Reynolds Creek Watershed numbered as shown in Figure 1 from the upper left (northwest) corner in rows of 10. In the Rabbit Creek Watershed, Figure 2, the regular section numbers are used. Each section is subdivided into 100 squares, as indicated in the subdivided section in the upper right corner of Figure 1. Within a numbered section, a location is found by moving down any section to the row, and then across to the proper column. A precipitation gage is designated by a 6-digit number. The first three digits represent the section and the last two digits represent the location of the smallest subdivision within the section.

TABLE 1.--Instrumentation

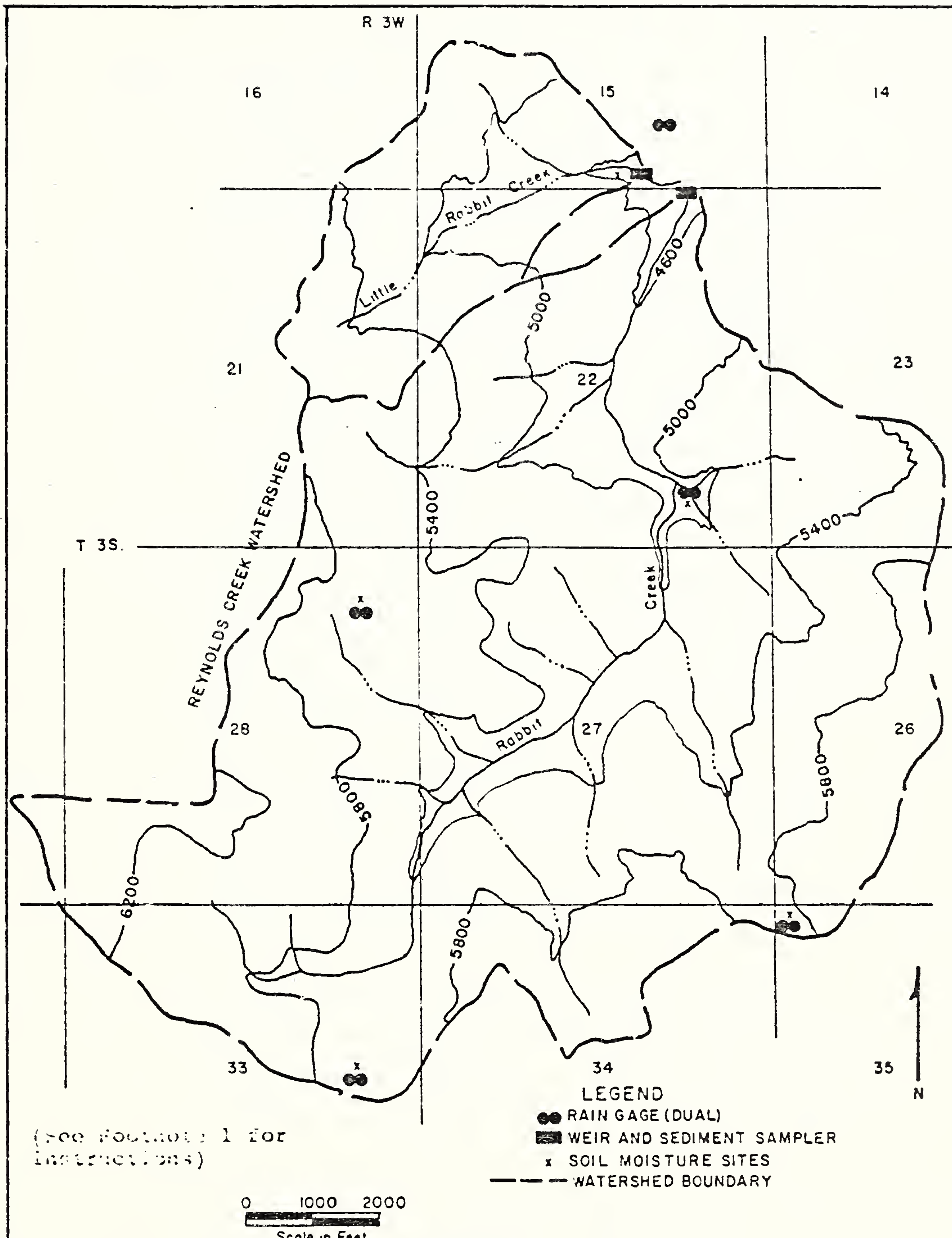
Location (See Figure 1, for Section Numbers and Footnote 1, p. 1-4 for location of sites)	Weirs	Recording Rain Gages (Dual Sites)	Recording Rain Gages (Single or Grouped)	Universal Surface Gages	Snow Courses	Snow Pillows	Soil Moisture Sites	Piezometers Obs. Wells	Solarimeters	Temperature-Humidity	Max.-Min. Thermometer	Soil Lysimeters	Anemometers	Pumping Sediment Samplers	Runoff-Sediment Plots
Reynolds Creek Watershed Network	4	96		1	8	2		19					2	2	
Murphy Cr. (43)	1														
Summit Study Basin (48 & 49)	1						24	8							
Lakebed Study Site (57)							3								
Cooperative Weather Sta. (76)			2						1	2	1		2		
Ground-Water Study Basin (86)	6 2/						14	30				2		1	
Nancy Gulch Study Area (98)							3								1
Sheep Creek (117) Watersheds (138)	3		1				31	10						1	
Climatological Stations (127)			1						1	1	1	2	1		
Reynolds Mt. Study Basins (166 & 176)	2			2		2	24	15						1	
Climatological Stations (176)			9						1	1	1	2	3		
Rabbit Creek	2	10					11							2	
Thompson Watershed (Moscow, Ida.)	1	2												1	
Bogus Basin				1		2									
Trinity Mtn.				1		2									
Totals	20	108	13	5	8	8	110	82	3	4	3	6	8	8	1

2/ Parshall Flumes



(See Footnote 1 for instructions)

FIGURE 1.



(See Footnote 1 for instructions)

RABBIT CREEK WATERSHEDS
OWYHEE COUNTY, IDAHO
JANUARY, 1970

FIGURE 2.

4. Cooperative Research

a. U.S. Department of Interior, Bureau of Land Management.

(1) The cooperative work in the Reynolds Creek Watershed is for comprehensive studies on the effects of vegetation upon the hydrologic performance of watersheds. The BLM furnishes supplemental funds and the required experimental sites on public lands as assistance in conducting these studies. The funds have been used primarily in support of investigations under Research Outlines Ida-Bo-105.4, 105.5, 105.6, and 106.1.

(2) Data on the Rabbit Creek Watershed (Frail Lands area) are collected, processed, and reported with operating funds supplied by the BLM District Office, Boise, Idaho. A map of the Rabbit Creek watershed, showing the data network, is included as Figure 2, I.7.

b. University of Idaho

(1) Studies of the ground-water flow system and water balance for an irrigated field (Research Outline Ida-Bo-103.3) has progressed to the final analysis stage. A Doctor's thesis by Mr. David Allman and papers covering this work will be prepared in 1971 and the Outline terminated.

(2) Field data on evapotranspiration obtained by use of micrometeorological instrumentation has been processed by Mr. George Belt and preliminary analyses made (Research Outline Ida-Bo-106.1). At least one paper will be prepared during 1971 covering the analysis of data obtained during 1969. Additional field data will be obtained in 1971.

(3) Collection of climatological, soil moisture, runoff and sediment data from the Thompson Watershed near Moscow, Idaho continued through 1970 under direction of Dr. Myron Molnau. Also, two gravity samplers for suspended sediment were designed and fabricated at the University for use on the Thompson and Reynolds Creek Watersheds.

c. University of Nevada

Data collection and analysis of the ionic concentrations in a ground-water flow system is approaching completion. (Research Outline Ida-Bo-103.4.) The chemical analysis has been performed by Dr. John Sharp of the Desert Research Institute.

[illegible] interpretation [illegible] and [illegible] elements.

(1) The [illegible] by [illegible] [illegible] [illegible] in the [illegible] [illegible] [illegible] of [illegible]. The [illegible] and the [illegible] [illegible] limits [illegible] [illegible]. The [illegible] [illegible] [illegible] of investigation [illegible] [illegible]-103.6, 106.1, 107.6, [illegible] 108 [illegible].

(2) Data on the [illegible] [illegible] [illegible] [illegible] are collected, [illegible] with other [illegible] [illegible] [illegible], Idaho. [illegible] [illegible], and in [illegible] [illegible] of Figure 3, [illegible]7.

[illegible] Idaho

(1) [illegible] [illegible] [illegible] [illegible]

d. Oregon State University

Work has continued on development of techniques and instrumentation for determining hydraulic properties of soils in the field by Dr. Royal Brooks and Mr. Neil Riggs. (This work is reported under Research Outline Ida-So-105.6.)

e. Utah State University

Investigations on the flow of water from an infiltrometer and two-dimensional flow systems have been conducted by Dr. Roland Jeppson and Mr. Chi-Yuan Wei. Reports have been prepared covering analytical solutions and laboratory data obtained for verification. (Work reported under Research Outlines Ida-So-105.5 and 105.6.)

B. HYDROLOGIC DATA

Hydrologic data collected from the instrumentation as listed in Table 1, p. 1-5, and as located in Figures 1 and 2 on Pages 1-6 and 1-7, respectively, have been tabulated or entered on punch cards for processing and analysis. These data for the water year of 1970 are included as an Appendix (attached to reserve-working copies of this Report) containing information on runoff, precipitation, snow water content, soil moisture, sedimentation, water-table depths, wind, solar radiation, and humidity.

REPORTS BY INDIVIDUAL EXPERIMENTS

CRIS Work Unit No. SWC-011-fBo-1 Code No. Ida-Bo-100.1

Title: Snow accumulation and melt on study areas.

Location: Northwest Watershed Research Center, Boise, Idaho.

Personnel: Lloyd M. Cox and Freeman M. Smith.

Date of Initiation: August 1, 1961.

Expected Termination: Originally planned, November 1968. Recommendation, November 1971.

Objectives:

1. To determine the physical and meteorological factors con tributing to nonuniformity of snow accumulation in shrub-covered study basins on mountainous terrane.

2. To determine the influence of the controlling physical and meteorological factors on snowmelt from the above areas.

Need for Study:

A substantial proportion of the runoff from the sagebrush rangelands of the Northwest has its origin in the melting of snow. Any proposals to improve the quantity or timing of flow from snow-fed streams by manipulation of vegetation or by other practices require that the behavior of snow be well understood. There has been little research on the behavior of snow in shrub areas anywhere, and almost none in the sagebrush areas of the Northwest.

Destructive late winter and spring floods in the Northwest frequently originate from rapid melting of snow at low elevations characteristic of the sagebrush zone. Although there is little likelihood of modifying snowmelt rates enough to alleviate this threat, knowledge about the behavior of snow in the sagebrush zone will be helpful in devising better warning and forecasting techniques that may reduce the danger to life and property from snowmelt floods.

Design of the Experiment and Procedure to be Followed:

Because of the exploratory nature of this experiment, no ordinary statistical design is applicable to the study. However, the general plan

is to choose two unit source areas--both shrub-covered--and at randomly located points, to determine the following variables: snow depth and water content, slope, aspect, vegetation height, total and net solar radiation, runoff, temperature, wind, and humidity. Multiple regression analysis will be used to identify the characteristics contributing to heavy snow accumulation.

The areas of heavy and light snow accumulation will be delineated by the use of photogrammetric techniques. The photogrammetric data will be used to construct cross sections to show snow depth in relation to ground-surface features.

Experimental Data and Observations:

Destructive flooding from melting snow is usually associated with a rain-on-snow event. The rain by itself adds very little heat to the snow to produce melting. What usually happens is that the condensation heat and also convective heat exchanges are also acting at the time of rainfall, thus contributing to snowmelt. If the snow is quite cold and the crystals quite fine, then the snow can be termed as dry and has the capacity to store water. A rain-on-snow event under these conditions may not produce any runoff until the storage capacity of the snow has been satisfied. Much depends, of course, on the existing meteorological conditions and the depth of the snowpack.

Figure 1[1/] is a graph depicting a rain-on- snow event with a snow depth of 11 inches and water equivalent of 1.28 inches. The curve at the top of the figure represents the changes of air temperature with time during this event. The next curve shows the changes in water equivalent with time as measured by a universal gage and the melt from this gage is represented by the second curve from the bottom. The bottom curve is a plot of the precipitation as collected with an 8-inch unshielded rain gage located adjacent to the site.

Precipitation was observed as rain from 0800 November 23, 1970, until 0100 on November 25, 1970. Even though the rainfall was not constant, water continued to flow out from the bottom of the snowpack at a fairly constant rate until 1600 on November 24, 1970. After this time, bursts of precipitation produced surges in the water being collected at the bottom of the snowpack, indicating that the storage capacity of the snow had been reached. With the cessation of rainfall at 0100 on November 25, 1970, water continued to drain from the snowpack until 1000 on November 25, 1970. Snow started to fall at 0700 on November 25, 1970, thus producing a subsequent increase in the water equivalent measurement.

1/ Figure 1 follows page 2-4.

The total precipitation collected by the unshielded rain gage for this event starting at 1000 on November 22, 1970, through 1200 on November 25, 1970, was 2.17 inches, while the shielded gage caught 2.4 inches. The water equivalent measurement showed a net increase of 1.10 inches, using a tentative calibration. The melt collected during this time period was 1.44 inches of water.

Comments, Interpretation and Future Plans:

Data collected during the rain-on-snow event showed that the net change in water equivalent for the event resulted in an increase of 1.10 inches of water. Total melt collected for this same period was 1.44 inches of water. Of the 2.17 inches of precipitation collected by the unshielded rain gage, 1.82 inches was observed as rain, the remaining was snow. This indicates that at least 0.38 inches of rain (1.82 -1.44 = 0.38 inches) was stored within the snowpack.

Data collected from another snow study site during this same rain-on-snow event did produce similar results in the total amount of melt water collected. Unfortunately the rain gage at this other site was not in operation and no precipitation was collected.

Previous studies (Research Outline Ida-Bo-102.6) have indicated that the precipitation caught in an unshielded rain gage is not representative of the actual catch. If the calibration coefficient, as determined from these studies, is used to calculate the actual precipitation using the unshielded total of 2.17 inches and the shielded total of 2.40 inches then a value of 2.67 inches is the total precipitation for this event. This would mean that about .13 inches more precipitation fell than could be accounted for by the increases of water equivalent and melt water collected (1.10 + 1.44 = 2.54 inches) by the universal gage. This is a very close agreement, considering that a tentative calibration was used for converting the pressure recording on the universal gage to water equivalent and that the calibration coefficient for the rain gages may be slightly different than a value of 2.0.

One other source of heat that can produce appreciable snowmelt comes from the long wave radiation that is radiated from the low warm cloud cover during the spring melt season. An effort was made to collect net radiation data during the previous spring snowmelt season, but this effort was unsuccessful because of instrument failures. Duplication of critical components in instrument recording systems is a must if continuous data are to be collected at remote snow research sites.

Sufficient replication of meteorological measurements and snowmelt collection measurements is necessary for adequate evaluation of heat energy flexes during special snowmelt events. Quality measurements of net radiation, solar radiation, precipitation, air temperature, relative humidity, windspeed, snow profile temperature, and snow density measurements along with simultaneous measurements of water leaving the bottom of the snowpack are all absolutely necessary for developing and testing a meaningful snowmelt model.

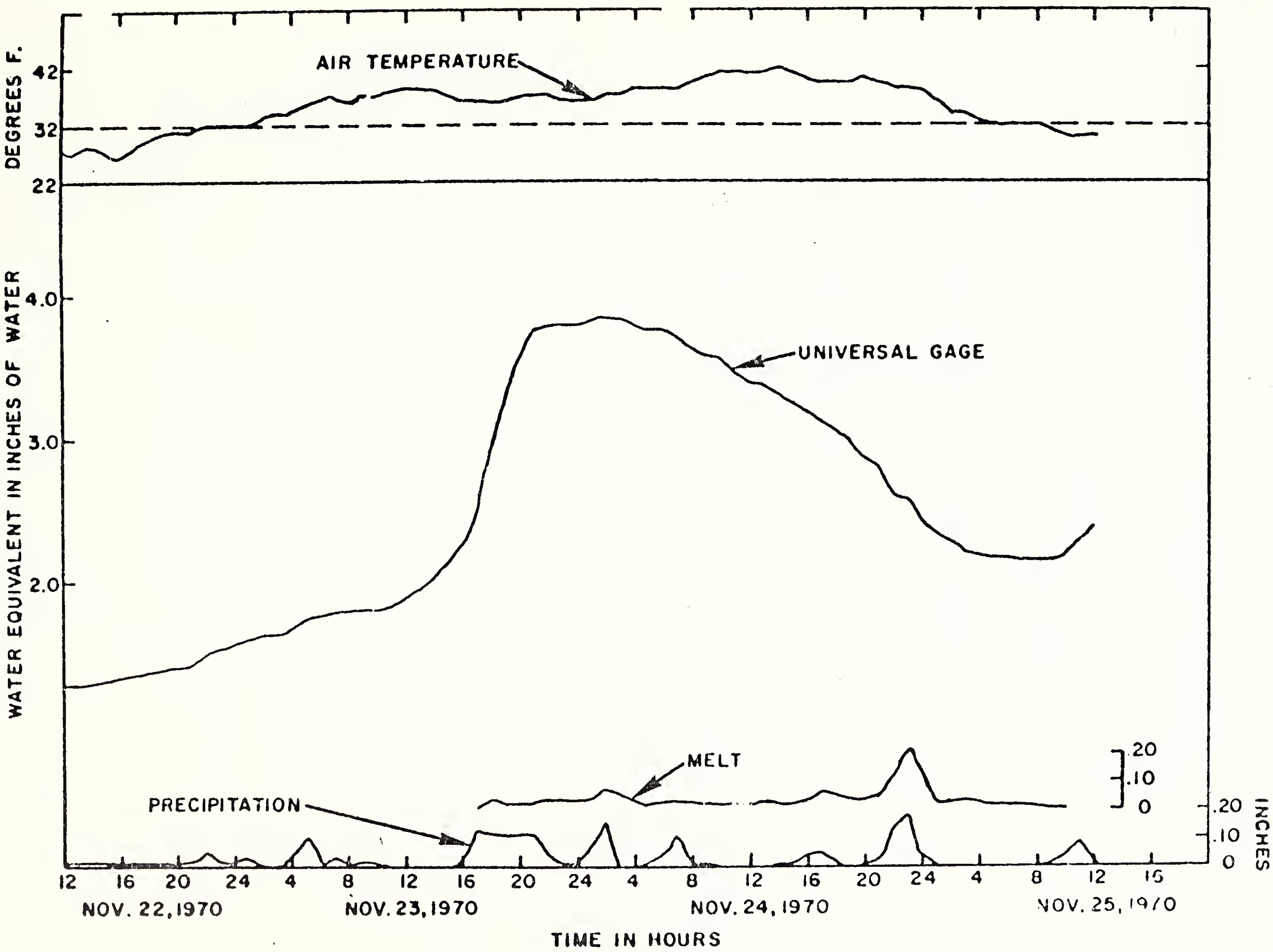


Figure 1. Changes in water equivalent with time as measured with a universal gage during a rain-on-snow

CRIS Work Unit No. SWC-011-fBo-1 Code No. Ida-Bo-102.1

Title:	Precipitation characteristics of a northern, mountainous, semiarid watershed.
Location:	Northwest Watershed Research Center, Boise, Idaho.
Personnel:	F. M. Smith[1/] and W. R. Hamon
Date of Initiation:	June 1961
Expected Termination Date:	Originally Planned: December, 1969 Recommended: December, 1971

Objectives:

1. To develop methods for evaluating precipitation rates and amounts for watersheds of different sizes.

2. To determine seasonal distribution of precipitation with respect to amounts, character, and areal extent.

3. To develop depth-duration-frequency and depth-area-duration relationships for the Reynolds Creek Experimental Watershed.

4. To establish general precipitation-elevation-aspect-slope relationships from precipitation data obtained in the Reynolds Creek Experimental Watershed.

Need for Study:

No dense recording rain gage networks exist in the Northwest. Such a network is necessary to delineate thunderstorms and storm variability. Furthermore, Weather Bureau data collection stations are generally located in or near the main cities. These cities are generally along the main stems of major streams or in their valleys. Thus a sample of the range watershed areas is not available from their records. In addition to this, there is a dearth of rain gages capable of recording intensities or even individual storm data.

The Soil Conservation Service is constantly called on to make estimates of precipitation away from the large population centers. Very little data is available to them on which to base their estimates.

1/ On leave without pay during reporting period.

Design of Experiment and Procedure to be Followed:

Data Procurement:

1. A recording rain-gage network with a basic density of one gage per square mile will furnish the basic data. At selected locations additional gages will be added to furnish data to obtain refinement of the spatial variability of precipitation.

2. Data on elevation, aspect, and slope will be obtained from topographic maps.

3. Comparable precipitation data will be obtained from U. S. Weather Bureau stations in the general region.

Procedure:

Precipitation-elevation-slope-aspect relationships will be established and basic data reduced to a common datum plane for storm analysis to obtain objectives.

Experimental Data and Observations:

Precipitation data collection was continued from the Reynolds Creek and Rabbit Creek network, Figures 1 and 2, pages 1-6 and 1-7, respectively. Data on the precipitation gage networks and other instrumentation is noted in Table 1, page 1-5.

Each precipitation site is instrumented with dual gages--one unshielded and one shielded gage. A mathematical model that uses the shielded and unshielded gage catches to computed "actual" precipitation, independent of wind, has been presented in previous Annual Report.

An isohyetal map of Reynolds Creek Expermental Watershed for precipitation caught by unshielded gages, during the 1969-70 water year is presented as Figure 1[2/]. Isohyets of the shielded gage catch in excess of the unshielded gage catch is shown in Figure 2. Computed precipitation totals, obtained from totals of shielded and unshielded gage catches, for the 1969-70 water year have been used to prepare an isohyetal map, Figure 3. Values obtained for this latter isohyetal map of computed total precipitation are up to 4 percent too small in the higher precipitation zones since yearly rather than storm or monthly totals were used in the calculations.

2/ Figures follow page 3-4.

Water year totals of unshielded and computed precipitation, along with runoff and evapotranspiration estimates, are tabulated for 4 watersheds in Table 1.

All previously obtained precipitation data are to be converted to better estimates of actual precipitation by applying procedures developed under Research Outline Ida-Bo-102.6.

TABLE 1.--Watershed precipitation, runoff, and evapotranspiration.

Watershed and Elevation Range, Ft.	Precipitation[1/] (U)	(A)	Runoff (R)	E.T. (A-R)	P.E.T.[2/]	U/A
	- - - - - -	- - - - - -	-Inches-	- - - -	- - - -	-(%)
Summit (4180-4800)	9.25	10.00	0	10.00	37	93
Lower Sheep (5200-5428)	11.55	14.88	0.03	14.85	32	78
Salmon (3675-6200)	16.26	18.85	3.45	15.40		86
Tollgate (4600-7300)	23.77	30.65	10.14	20.51	29	78

1/ The symbol U represents unshielded precipitation gage catch and A computed ~~shielded gage catch~~. precipitation.

2/ P.E.T. represents potential evapotranspiration. Value extracted from 1968 Annual Report.

Comments, Interpretations, and Future Plans:

The computed water year precipitation, Figure 3, for the Reynolds Creek Watershed exceeds the precipitation caught by unshielded gages by about 1 inch where the total precipitation caught by the unshielded gage was only 10 inches, but exceeds the unshielded gage catch by nearly 14 inches at higher elevations where the total unshielded gage catch was about 31 inches. Expressed as percentages, the observed unshielded precipitation gage catches were about 89 percent of the computed values where totals were about 10 inches, but only 69 percent at the highest elevations where the total unshielded catches were near 31 inches. The greater percentage of precipitation occurring as snow and the higher wind speed at the higher elevation contribute to the resulting smaller percentage of actual precipitation being caught by the unshielded gage.

Water balance studies and runoff models require reliable input data if results are to have any applicability to areas outside the study area. In the case of Reynolds Creek Watershed, inadequate precipitation data would make it impossible to develop and test predictive hydrologic models. The importance of realistic precipitation data is demonstrated by the data on watershed precipitation, runoff, and evapotranspiration presented in Table 1. The evapotranspiration estimates in this table are obtained by use of the water balance equation with storage changes neglected.

As demonstrated in Table 1 for 4 watersheds within the Reynolds Creek basin, the unshield precipitation gage catches (U) are completely unrealistic. Use of these values would indicate an evapotranspiration lost for the water year of only 13.63 inches for the Tollgate watershed as compared to an estimated potential evapotranspiration of 29 inches. In comparison, the computed precipitation value for the watershed is 67 percent of the potential evapotranspiration. On the basis of computed precipitation and runoff data, Table 1, essentially no water yield occurred in the area receiving less than 15 inches of precipitation for the water year or for elevations less than 5200 feet.

Refined procedures for computed actual precipitation, as developed under Research Outline Ida-Bo-102.6, will be utilized to obtain realistic values of precipitation to be used in the required analyses to reach the objectives of this Outline.

A paper [3] has been prepared on the Reynolds Creek precipitation gage network. It contains information on the dual gage procedures and on tentative precipitation-elevation relationships.

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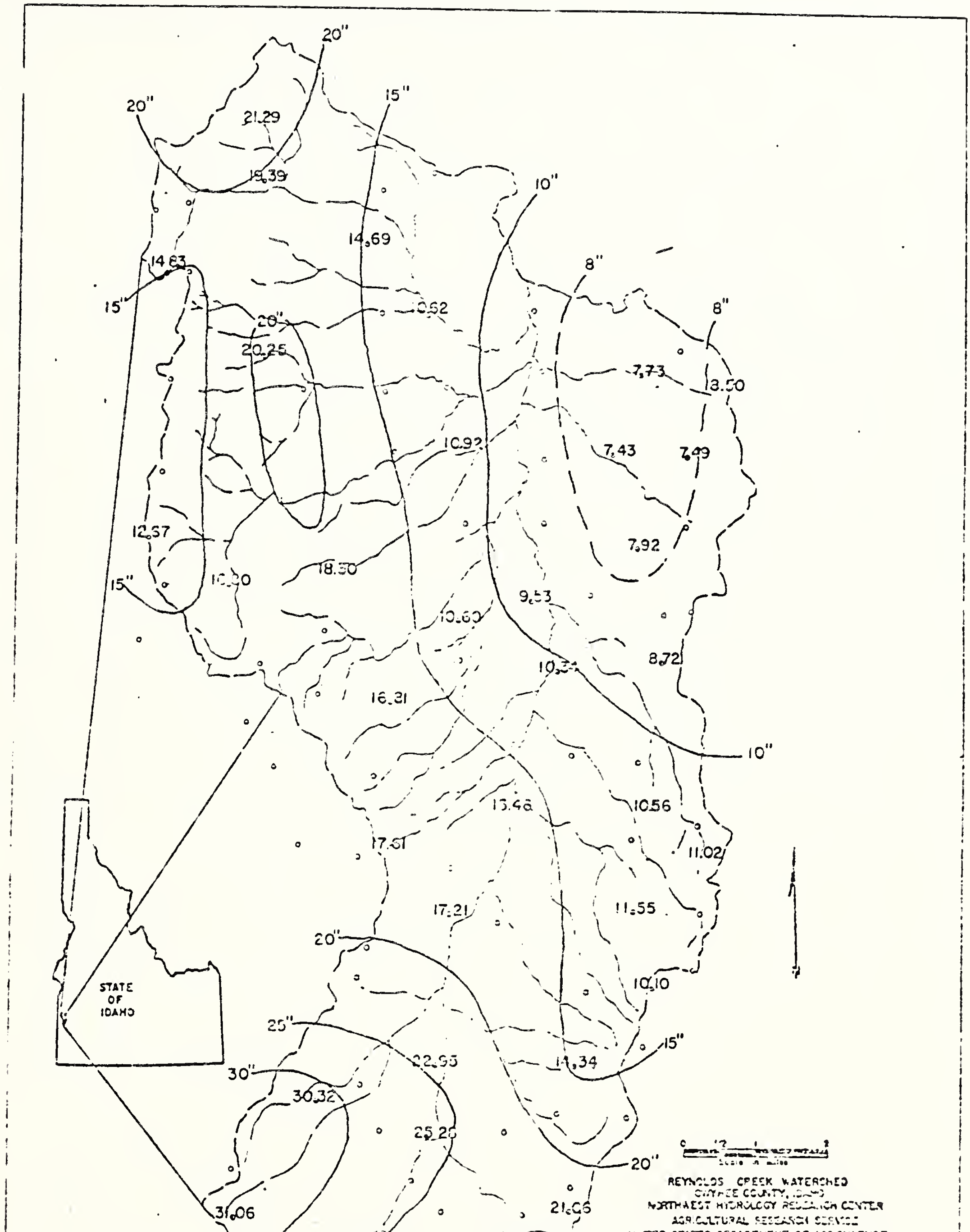
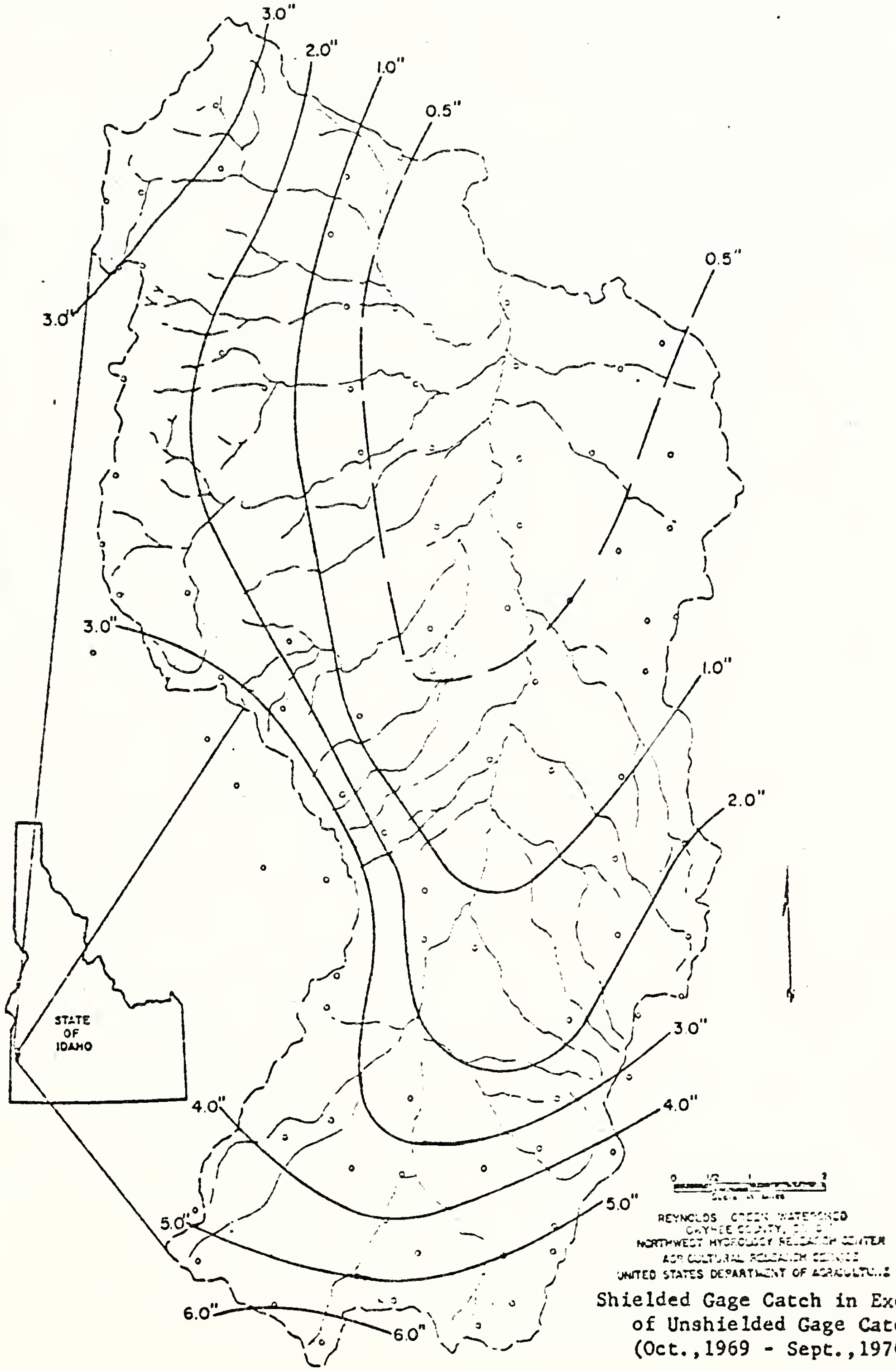
[3] Hamon, W. R. The Reynolds Creeks Precipitation Gage Network in Southwestern Idaho. Approved by Division for publication in, ARS Precipitation Facilities and Related Studies, ARS 41-176 (Edited by D. M. Hershfield).



Precipitation

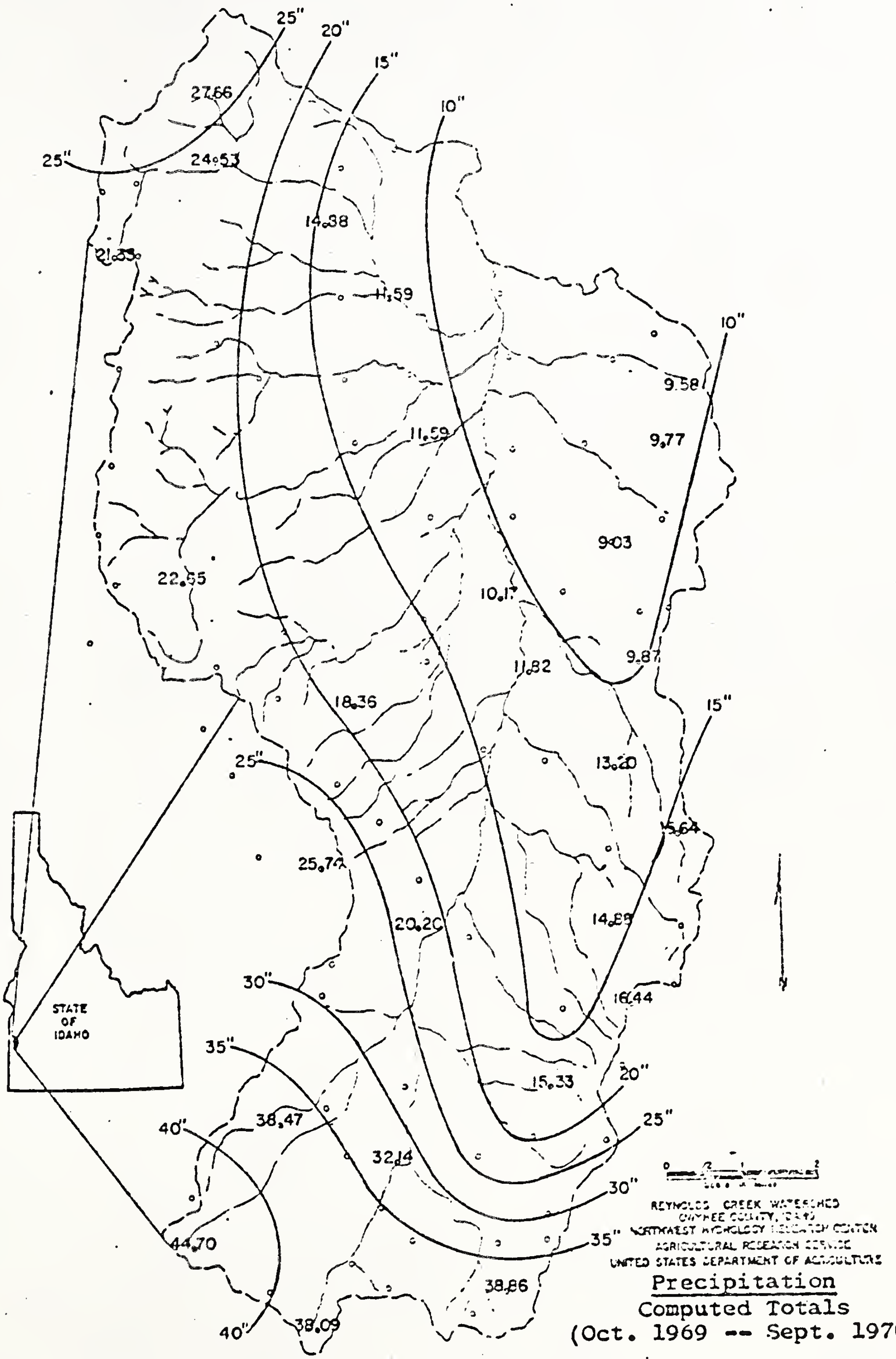
(Unshielded gage catch)
Oct., 1969 - Sept., 1970

FIGURE 1



Shielded Gage Catch in Excess
of Unshielded Gage Catch
(Oct., 1969 - Sept., 1970)

FIGURE 2



Precipitation
Computed Totals
(Oct. 1969 -- Sept. 1970)

Figure 3

CRIS Work Unit No. SWC-011-fBo-1 Code No. Ida-Bo-102.6

Title: Evaluation of precipitation gage performance.

Location: Northwest Watershed Research Center, Boise, Idaho

Personnel: F. M. Smith[1/] and W. R. Hamon.

Date of Initiation: December 1964.

Expected Termination Date: Originally Planned: July 1, 1969.

Recommended: December 1971.

Objectives:

1. To determine which of several commercially available precipitation-measuring devices most accurately measure the actual amount of precipitation.

2. To develop criteria and specifications for installing precipitation gages to provide the most accurate measurements of precipitation.

3. To develop methods and procedures for adjusting records from precipitation gages with "standard" installations to more accurately reflect the point precipitation.

Need for Study:

Man has always been interested in precipitation because of his dependence upon it to sustain his way of life. First efforts to systematically measure rain are lost in antiquity, but they probably coincided with the early development of the art of making clay bowls and vessels. Writings from as early as 400 B. C. describe containers with standard dimensions being used to collect rainfall for forecasting agricultural conditions.

The art of measuring precipitation has changed little in the past 2500 years. Modern-day gages are still simple containers with well-defined dimensions in which the catch is measured by reference to a standard volumetric container, use of a dip stick, or by weighing. Accepted practice is to place gages, when possible, at locations that are

1/ On leave without pay during reporting period.

protected from the direct sweep of the wind and are no closer to buildings, trees, fences, etc. than three times the height of these objects.

In intensive hydrologic investigations, it is important to know as precisely as possible the input of precipitation to small watersheds or study areas. This requires two things: (1) a gage network of sufficient density to adequately sample the aerial variability of the precipitation, and (2) devices that will accuarely measure the precipitation at a point. The first of these, network density, can be determined by standard statistical sampling procedures. For the second, however, it is questionable whether or not modern-day precipitation gages will provide accurate, quantitative point measurements. To resolve this question, an evaluation of the performance of precipitation gages under varying conditions of topography, exposure, and wind is required. It is only after such an evaluation is made that data from either individual gages or networks can be used with confidence.

Design of Experiment and Procedures to be Followed:

Evidence to date indicates questionable accuracy of precipitation data from gages at windy exposures. Experiments have demonstrated gross inaccuracies in snow catch under windy environments. In this study an attempt will be made to determine: (1) Whether or not there is a difference between the amount of precipitation caught in the various gages and the assumed "true" catch of a pit gage; (2) if there is a difference, what factors of wind, installation technique, topography, orientation, etc. cause the difference; (3) the criteria for assessing the site selection, type of gage, and installation techniques under various physiographic conditions to provide more accurate measurement of the amount of precipitation that reaches the ground surface; and (4) procedures and techniques based on site characteristics to correct precipitation records.

Sites will be selected on the Reynolds Creek Experimental Watershed that are representative of the major topographic-elevation complexes. At each of these study sites precipitation measurements will be made by using an unshielded gage and shielded gage with orifices at the same height and exposed to horizontal wind movement. The same installation will be made at special evaluation sites with the following additional installations: (1) unshielded gages in a vertical profile, (2) snow pillows, (3) sunken precipitation gage, (4) vectopluviometer, and (5) anemometers.

Data obtained from profile measurements of precipitation and wind will be used to compute the actual vertical flux of precipitation. These computed values for windy, snowy conditions and data from snow pillows and

a vectopluviometer will be used to calibrate the relative catches of shielded and unshielded gages to obtain estimates of actual precipitation. These generated data will be used in a relationship between catch, wind, and temperature for correcting the catch of a single gage to account for the wind effect.

Experimental Data and Observations:

Data collection continued at the precipitation gage evaluation site on Reynolds Mountain (176 X 14), at the snow pillow site (176 X 07) about one-fourth mile to the east, and at the dual-precipitation gage site (166 X 94) about one-fourth mile to the north. The types of data collected at the 3 sites are indicated in Table 1.

The tipping-bucket, heated, gages were added to the experimental site during the fall of 1969, but little useful data were obtained during the snow season of 1969-70 because of heater blowout or failures.

TABLE 1.--Data collected at sites on Reynolds Mountain for evaluation of precipitation gage performance.[1/]

Types of Data and Height of Sensor, Ft.	Sites[2/]		
	176 X 14	176 X 07	166 X 94
U (3 1/2)	X		
U (5)	X		
U (7)	X		
U (10)	X	X	X
U (14)	X		
S (5)	X		
S (10)	X	X	X
W (5)	X		
W (7)	X		
W (10)	X	X	
U_h (10)	X		
S_h (10)	X		
SP		X	
SC		X	

1/ Instrumentation: U is recording unshielded gage; S is recording shielded gage; U_h is tipping-bucket, heated, unshielded gage; S_h is tipping-bucket, heated, shielded gage; W is recording anemometer with wind vane; Sp is snow pillow, and SC is snow course.

2/ Instrument sites can be found in Figure 1, page 1-6. (Also see Footnote 1/ on page 1-4.)

Comments, Interpretations, and Future Plans:

Sufficient data will have been obtained at the close of the 1970-71 snow season to complete the evaluation of precipitation gage performance and to establish firm values for the coefficients in the mathematical model to be used in calculating "actual" precipitation. This model, as developed in the 1968 Annual Report, is as follows:

$$\frac{S}{A} = e^{-aW} \qquad (1)$$

$$\frac{U}{A} = e^{-bW} \qquad (2)$$

$$\frac{U}{S} = e^{-(b-a)W} \qquad (3)$$

$$\log_e \left(\frac{U}{A}\right) = B \log_e \left(\frac{U}{S}\right) \qquad (4)$$

$$B = \frac{b}{b-a} \qquad (4a)$$

$$\log_e \left(\frac{S}{A}\right) = C \log_e \left(\frac{U}{S}\right) \qquad (5)$$

$$C = \frac{a}{b-a}$$

where A is the computed "actual" precipitation; U is the unshielded gage catch; S is the shielded gage catch, a and b are coefficients, and B and C are termed calibration coefficients.

The model requires data from the shielded and unshielded gages with orifices at the same height (high enough to escape blowing snow) and a rigid shield (constrained leaves at an angle of 30 degrees from the vertical) on the shielded gage.

Profile data on precipitation catch and profile windspeed, snow pillow and snow course data, and data from the unshielded and shielded gages (10 feet) at the 3 sites (Table 1) have been used to establish a tentative value of the calibration coefficient, B, or

$$B = \frac{b}{b-a} \sim 2.0 \qquad (6).$$

This calibration coefficient will be more accurately established when sufficient data have been obtained which should be achieved during the snow season of 1970-71. It has, however, been reasonably established that the calibration coefficient is not a function of type of precipitation.

With an established value of the calibration coefficient, B, in Equation 4, the "actual" precipitation can be computed by use of measured precipitation by an unshielded and shielded gage. (Equation 5 is equally applicable since C is also known.)

Precipitation data, however, are universally obtained by either an unshielded or shielded gage except for the dual gage network that was established in the Reynolds Creek Experimental Watershed in late 1968. The earlier data in the watershed and data elsewhere need to be adjusted for more adequate estimates of actual precipitation, particularly where snow is the precipitation type.

Data for the period, November 1967 to December 1970, including data on windspeed, temperature, and catches by unshielded and shielded gages, have been analyzed to establish procedures for adjusting catches by either a shielded gage or unshielded gage of the type used in the study.

Data for 122 storms in excess of 0.1 inch were grouped according to the following 4 temperature ranges:

1. $t > 35° F.$
2. $32° < t \leq 35° F.$
3. $32° \geq t > 23° F.$
4. $9° < t \leq 23° F.$

with plotting made of values for U/S and for wind (W) on semilogarithmic paper, according to Equation 3, in Figures[2/] 1 and 2. Curves drawn through the origin and mean are shown in the figures and grouped in the bottom graph of Figure 2. From these curves, the value of the coefficient, a, was established for each temperature range as shown in Table 2. With a reasonable estimate of the calibration coefficient, B, known (Equation 4), values of the coefficient b are established. Equations 1 and 2 can now be used to compute actual precipitation, given measured precipitation by either an unshielded or a shielded gage and data on wind and temperature. It is significant to note that with B = 2.0, (b-a)= 1.0a, and the ratio U/S is replaceable by S/A in Figures 1 and 2.

2/ Figures follow Page 4-8.

TABLE 2.--Coefficients to correct for the effect of wind and temperature on precipitation caught by shielded and unshielded precipitation gages.

Coefficients	For $B = \frac{b}{b-a} = 2.0$			
	Temperature, °F.			
	$t > 35°$	$32° < t \leq 35°$	$32° \geq t > 23°$	$t \leq 23°$
a	0.070	0.017	0.030	0.053
b	0.014	0.034	0.060	0.106
		Note: b = (2.0 X a)		

The derived coefficients are used in Equations 1 and 2 to obtain values of the ratios of shielded and unshielded gage catches to actual precipitation for two selected windspeeds and the results noted in Table 3.

The research task remaining is to establish a reliable value of the calibration coefficient and to test its variability with different types of dual gage installations. Further tests are to be made on the use of heated gages to eliminate the capping and riming of gages that invalidates the use of the collected data in any fashion.

TABLE 6.--Values of the ratio of unshielded, U, and shielded, S, gage catch to computed "actual" precipitation, A, for ranges in temperature and for two windspeeds.

Ratio and Windspeed	Temperature, °F.			
	$t > 35°$	$32° < t \leq 35°$	$32° \geq t > 23°$	$t \leq 23°$
W = 10 m.p.h.				
U/A	0.87	0.71	0.55	0.35
S/A	0.93	0.84	0.74	0.59
W = 30 m.p.h.				
U/A	0.66	0.36	0.17	0.04
S/A	0.81	0.60	0.41	0.20

A report[4/] has been prepared outlining the aspects of the dual gage and profile techniques for calculating actual precipitation.

4/ Hamon, W.R. Dual gage and profile techniques for calculating actual precipitation. Working Group on Measurement of Precipitation. Commission for Instruments and Methods of Observations, World Meteorological Organization, Geneva, Switzerland, October 1970.

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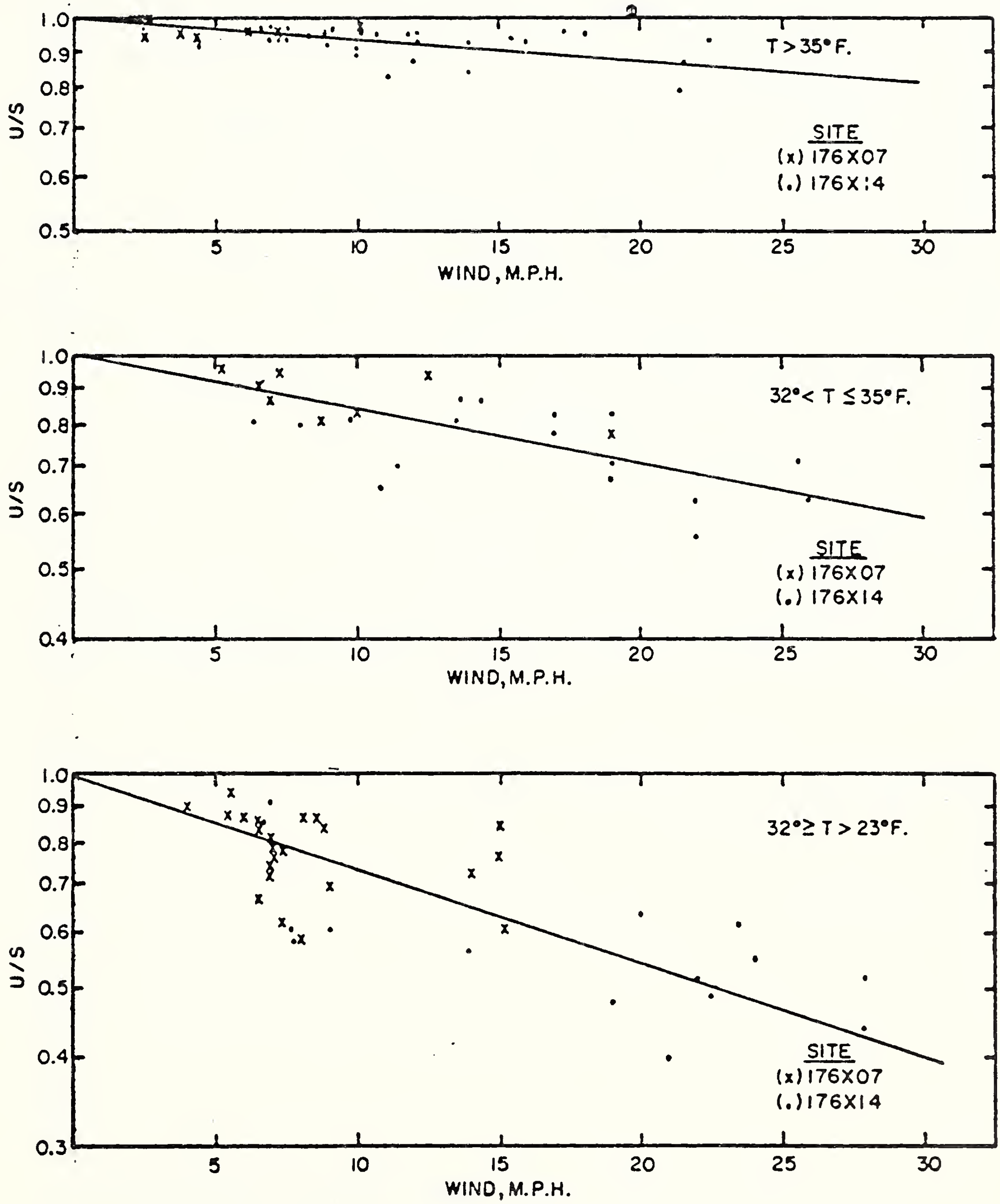

Figure 1. Ratio of unshielded (U) to shielded (S) gage catches in relation to wind and temperature.

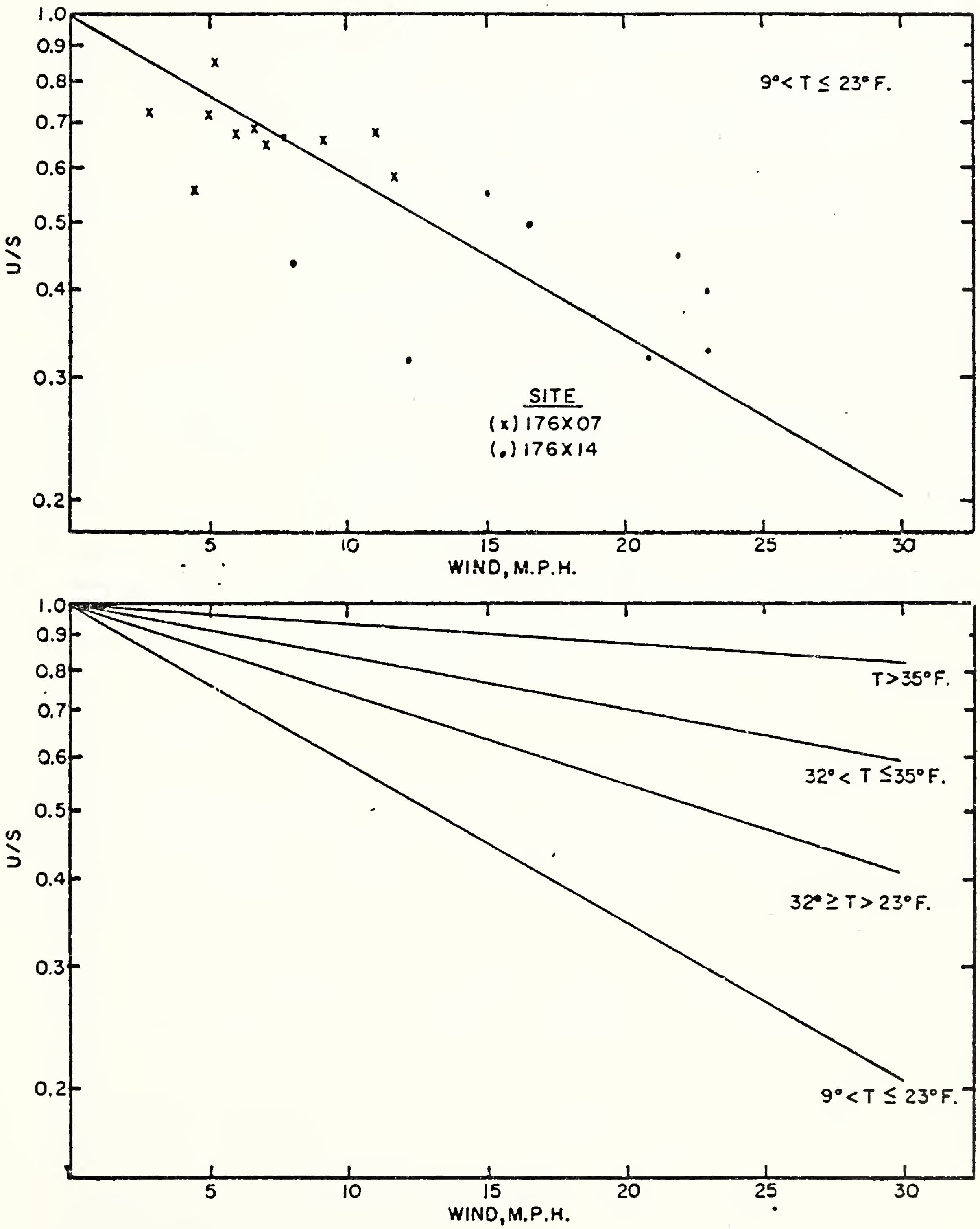

Figure 2. Ratio of unshielded (U) to shielded (S) gage catches in relation to wind and temperature.

CRIS Work Unit No. SWC-011-fBo-1 Code No. Ida-Bo-102.7

Title: Evaluation of pressure pillows, and hydraulic weighing and catchment devices for snow and precipitation measurements.

Location: Northwest Watershed Research Center, Boise, Idaho.

Personnel: L. M. Cox and W. R. Hamon; M. W. Nelson and J. A. Wilson, SCS.

Date of Initiation: September 1967

Expected Termination: Originally planned, August 1969.

Recommendation, July 1971.

Objective: To determine accuracy and utility of steel diaphragms, butyl or plastic pressure pillows, and a combination hydraulic-weighing and catchment device, for use in SCS snow surveys and ARS hydrologic research studies.

Need for Study:

The Soil Conservation Service is currently using many types of pressure-sensing devices to measure snow-water content. Measurements obtained by 12-foot-diameter pressure pillows have been superior to those obtained by snow-tube sampling. These pillows made of butyl or plastic, however, are subject to leakage and physical rupture. The initial cost is excessive.

Field tests are necessary to determine the accuracy and utility of new types of snow-water-measuring devices. Data obtained by such devices need to be correlated with snow-tube measurements to make past records fully useful in the preparation of water supply forecasts.

Besides the measurement of snow-water content, a universal device is needed that will also measure the total precipitation and snowmelt. The availability of snow-water content and total precipitation data each day is essential for the prediction of peak flows, low flows, and monthly increments of flow. Data obtained by such devices are required for hydrologic-water balance studies.

Design of Experiment and Procedure to be followed:

1. Commercially available 12-foot diameter butyl or neoprene pillows will be used as standards for comparisons. Steel diaphragm pillows will be constructed to SCS standards. A universal gage to measure snow-water content, total precipitation, and snowmelt will be an ARS-designed instrument. Installations will be as noted in Table 1 below:

TABLE 1. -- Snow pillow installations

	Locations			
	Reynolds Mtn.	Bogus Basin	Atlanta Summit	Trinity Mtn.
Elev. in feet (m.s.l.)	6,800	6,120	7,500	7,780
Av. Snow depth in feet (Est.)	5	6	8	10
Butyl/plastic pillow (12-ft. diameter)	*1/	X2/		X
Steel pillow (4 ft. by 5 ft.)	*	*		*
Steel pillow (4-4 ft. by 5 ft.) (grouped)	*		*	*
Universal gage (8-ft. diameter)	*	*		*

1/ New installation.
2/ Established.

2. All instruments will be calibrated with the 12-foot pressure pillow and independent calibrations obtained by gravimetric measurement of snow-water content. Samples will be obtained by snow tube and by other feasible methods.

Experimental Data and Observations:

Snowfall for the 1969-70 snow season was quite heavy with accumulations at the higher elevations approaching those of the previous year. Travel to the Atlanta Summit and Trinity Mountain sites was very difficult. Some snowmelt data were collected at Trinity Mountain but hazardous travel conditions prevented regular servicing of the recording equipment.

The Soil Conservation Service is in the process of installing a new telemetering system at the Trinity Mountain study site. This new system has a greater range plus the capability of handling more inputs from different sensors. The SCS plans to install new equipment to telemeter the water equivalent measurements from two 8 by 10-foot steel pillows and the universal gage. Once the system is working, a transducer will be added to telemeter the data from the melt collector of the universal gage. The 12-foot butyl pillow at this site developed an unrepairable leak, and it was replaced with another 8 by 10-foot steel pillow. The 12-foot butyl pillow at the Bogus Basin site has also been replaced with an 8 by 10-foot steel pillow.

Correlation coefficients for pressure-pillow response and snow-course measurement are given in Table 2. At both the Reynolds Mountain and Bogus Basin study sites, all measurements were equally correlated for the total snow season. In the past it was found (last year's Annual Report) that all measurements usually correlate very well during the accumulation period, but show a distinct lower correlation during the melt period. The 12-foot butyl pillow performs somewhat differently during the melt period as compared to the universal gage. This difference in performance appears to be closely related to the rate of snowmelt with low snowmelt rates giving good correlations and high snowmelt rates reduced correlations.

The longer the snowmelt is delayed in the spring by cool, cloudy weather, the greater is the potential for higher snowmelt rates. As the spring season progresses, more energy becomes potentially available to melt the snow because of the occurrence of higher air temperatures and subsequently greater vapor pressure gradients thus increasing convection and condensation melt; higher sun angles for greater radiation melt; and a greater opportunity for the advection of heat energy from bare soil surfaces to the existing snowpack. The performance of snow pillows during a period of late season melt is demonstrated in Figure 1.[1/] This graph shows the changes in water equivalent of the snowpack, with time as measured with a 12-foot butyl snow pillow (top curve) and a universal gage (middle curve). The

1/ Figure 1 follows page p. 5-6.

TABLE 2.--Correlation coefficients for pressure-pillow response and snow-course measurements.

Units Correlated	Reynolds Mountain and Bogus Basin Sites Combined
Univ. Gage by 12-foot butyl	.95
Snow Course Measurement by 12-foot butyl	.95
Snow Course Measurement by Univ. Gage	.94

snowmelt rate as collected and measured with a universal gage is shown at the bottom of the graph. These data were collected at the Bogus Basin snow research site with about 51 inches of snow and 23.0 inches of water equivalent.

The changes in water equivalent of the snowpack as measured by the 12-foot butyl pillow shows (with one exception) a continuous linear decrease with time for the four-day period. This exception was brought about by a rainstorm that occurred at 1400 to 1600 on May 19, 1970. No rain gage is located at the site so no estimate of the total precipitation during this time period was possible. The pillow measurement shows a characteristics increase when the rain first fell on the snow and a sharp decrease as the water started coming out of the bottom of the pack as indicated by the melt collected. (A further discussion of rain-on-snow can be found in Research Outline Ida-Bo-100.1). The 12-foot butyl pillow measurement does not show the decrease in melt per day as indicated by the daily decrease in snowmelt collected. Very little evidence of the diurnal melt pattern is reflected in the 12-foot butyl pillow measurement.

The water equivalent as measured with the universal gage does demonstrate three distinct slopes for the water equivalent changes during the four-day period. Each particular slope corresponds to a specific melt period with decreasing slope being associated with decreasing melt. The water equivalent as measured with the universal gage follows the diurnal melt cycle much better than it follows the 12-foot butyl pillow. The heavy rainstorm that caused the disruption in the 12-foot butyl pillow measured on May 19, 1970, was not as noticeable in the universal gage measurement.

From 1600 on May 17, 1970, to 0900 on May 20, 1970, the decrease in water equivalent of the snowpack as measured with the universal gage was 2.75 inches as compared to 2.10 inehes for the butyl pillow. The total amount of water collected from the bottom of the snowpack was 4.80 inches during this same period. This would indicate that at least (4.80 -2.75 = 2.15) 2.15 inches of water leaving the snowpack came from the rainstorms and condensate. Boise valley air temperature ranged from a low of 49°F. to a high of 65° F. during the period. Up to 0.50 inch of rain was recorded in the valley, but heavier storms are usually the rule for this research area which is about 4400 feet higher in elevation. Measurements of precipitation, air temperature and relative humidity are very urgently needed at this site for a more complete evaluation of the snowmelt process.

Comments, Interpretations, and Future Plans:

The feasibility of maintaining Atlanta Summit and Trinity Mountain as research sites was recently questioned because of the increased travel time required to service those sites. Further discussion revealed that these are the only deep snow sites (8-10 feet) we have and that Trinity Mountain is also one of the most important snow course measurement sites. Data from this site are used to predict streamflow into the Boise River irrigation and flood control complex. Because of its great importance for streamflow forecasting, the decision was made to maintain the Trinity Mountain site.

With the installation of the new SCS telemetering system, the potential for better data collection from this site will be greatly increased. This new system will make it possible to telemeter all types of meteorological data from both Trinity Mountain and Atlanta Summit. Measurements of air temperature, relative humidity, windspeed, soil temperature, snow temperature and radiation will be made as soon as economically possible.

The 12-foot butyl pillows are being gradually phased out. On the average, the life of these pillows is only about five years. They are being replaced by the cheaper and more versatile 8 by 10-foot steel pillows.

The difference in the slopes of the water equivalent measurement (Figure 1) as made by the universal gage and the 12-foot butyl pillow clearly demonstrate why the two units have a lower correlation during the melt period. During long periods of high melt, water temporarily mounds on the surface of the 12-foot butyl pillows, thus giving a false impression as to the time melt rate. In an old ripe

snowpack, the universal gage does not exhibit this effect, because as water is added to the snow by rain or melting, it runs out through the collector at the bottom. Very little water is held in the old snow to temporarily increase the water equivalent measurement. New, cold, low density snow would act to the contrary and under certain conditions, much of the rain added to the snowpack may not run out the bottom. (See Research Outline Ida-Bo-100.1.)

Downstream runoff predicted from water equivalent measurements from a 12-foot butyl pillow would obviously be in error during periods of high continuous melt. Many forecasters in the Western United States are currently using telemetered water equivalent data from 12-foot butyl pillows. The true measure of what is happening is indicated by the melt collected from the bottom of the snowpack. This method also gives additional information on condensation water and rainwater.

This study has brought further questions to mind concerning the procedures to collect snowmelt. This research outline will be terminated following the 1970-71 snow season. A new outline will be initiated and will involve a a study concerning what size of melt collected is required for accurate measurements of snowmelt. Also more study is needed on the rate at which melt water can be removed from a snowpack and still maintain a representative sample of current melt conditions. Under high melt conditions, if the water is removed too fast, then a greater area may be drained than the area of the collector.

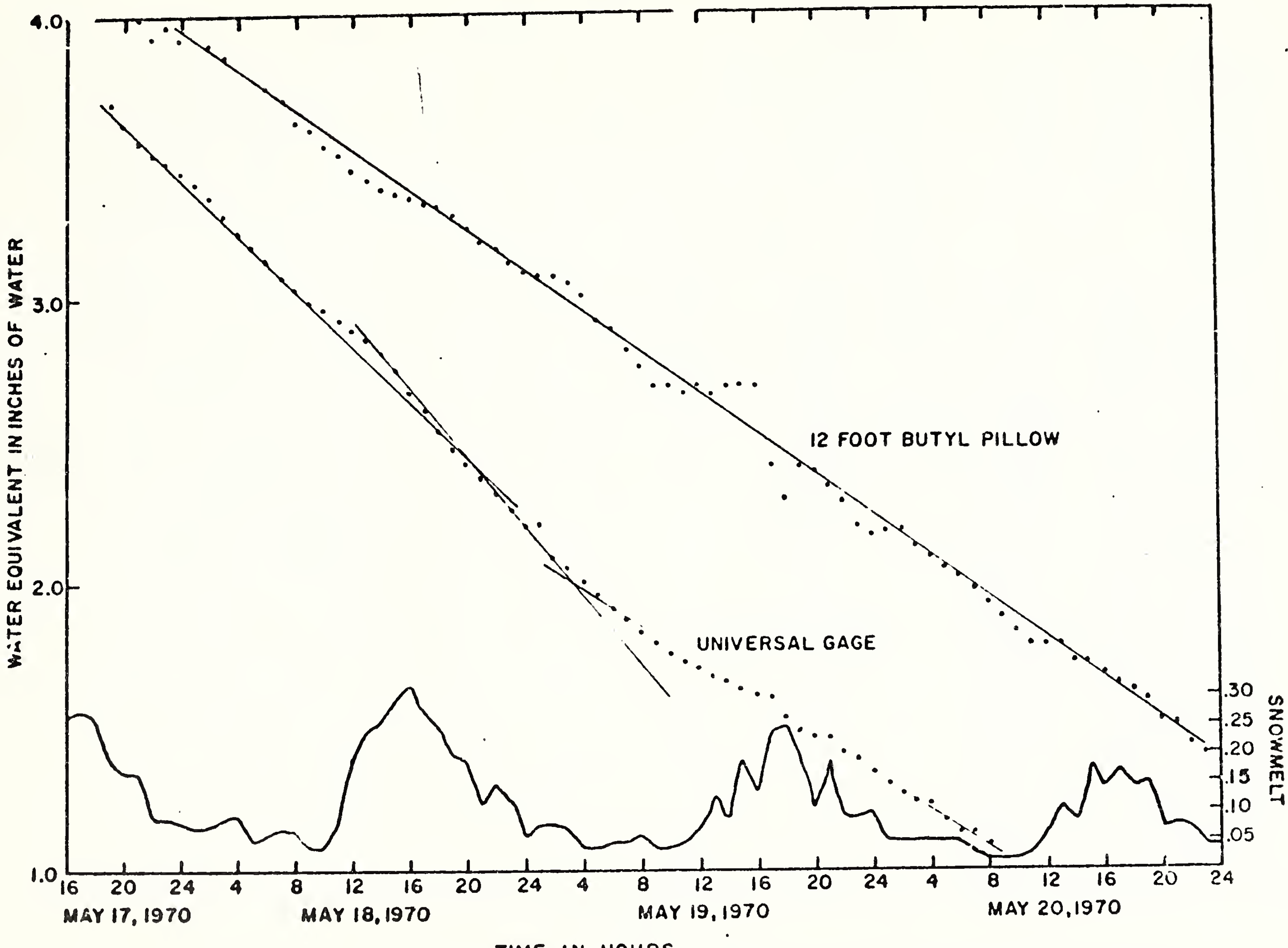

Figure 1. Changes in water-equivalent with time as measured with a 12-ft. butyl snow pillow and a universal gage during late season snowmelt. Indicated snowmelt was collected from the 57-inch snowpack using the melt catchment system of the universal gage.

CRIS Work Unit No. SWC-011-fBo-1 Code No. Ida-Bo-104.1

Title: Resistance coefficients for steep-rough channels.

Location: Northwest Watershed Research Center, Boise, Idaho.

Personnel: C. W. Johnson, and W. R. Hamon, D. E. Overton (USDA Hydrograph Laboratory); and Dr. H. E. Judd (cooperating through Utah State University)

Date of Initiation: March 1967

Expected Termination Date: Originally Planned: December 1970
Recommended Termination: July 1971

Objectives:

1. To test the applicability of classical flow resistance equations to flow data from natural channels in the Reynolds Creek Experimental Watershed.

2. To characterize channel geometry and bed roughness elements for use in investigating resistance coefficients.

3. To determine the relationship of the friction factor or roughness coefficient to channel characteristics.

Need for Study:

The prediction of the resistance to flow of natural streams is vital to the ultimate goals of mathematical simulation of the hydrologic performance of upland watersheds. The successful routing of runoff through a complex watershed stream-system is directly dependent upon an adequate prediction of channel resistance. Field research is needed to develop quantitative procedures for the representation of resistance coefficients; i. e., friction factors or roughness coefficients from easily-obtained field data on channel dimensions, and on size and spacing of roughness elements. Field engineers need an objective procedure for predicting depth of flow associated with the design discharge in the design of water-conveyance channels and streambank protection works.

Design of Experiment and Procedure to be Followed:

Cooperation of the USDA Hydrograph Laboratory, Utah State University, and the Northwest Watershed Research Center is continuing until analysis of available data from laboratory flumes and natural channels is complete. A thorough understanding of flow resistance in laboratory flumes is a necessary prerequisite to analysis of roughness in natural channels. A study of the effect of laboratory channel roughness parameters on flow resistance is progressing through the use of computers and results should be helpful in analyzing the more complex problem of roughness measurement in natural channels.

Data on channel geometry, stream discharge, size and spacing of roughness elements and slope of the water surface or channel are used to determine channel resistance. The Chezy equation

$$Q = C A' \sqrt{R' S}$$

and Darcy-Weisbach equation

$$Q = A' \sqrt{\frac{8 g R' S}{f}}$$

are used to determine resistance or roughness coefficients C and f, where Q is discharge, A' is cross-sectional area of the channel, R' is the hydraulic radius (both A' and R' denote inclusion of a roughness parameter), S is the energy slope (bedslope for uniform flow), and g is the acceleration of gravity.

Channel reaches on Reynolds Creek Experimental Watershed streams are instrumented to provide data from natural streams and existing structures are utilized where possible.

Experimental Data and Observations:

Analysis of a great bulk of data from laboratory flumes and natural channels was completed during the reporting year and no additional field data were collected. The determination of relationships between the resistance coefficient and parameters such as effective depth, roughness intensity, channel width and mean size of bed material was not equally applicable to laboratory flume studies and natural stream channels with large bed elements.

Comments, Interpretations, and Future Plans:

A procedure was developed for locating the plane of zero velocity near the channel bottom of laboratory flumes and natural streams with large bed elements. Also, an equivalent spacing for randomly-spaced bed elements was developed by use of regularly-spaced patterns of hemispherical bed elements in a laboratory flume. The random bed elements produced greater roughness coefficients than regular patterns of equal roughness intensity and increased the energy losses from 34-61 percent of that from regular patterns tested. Further, a study of wall effect in laboratory flumes of various widths showed that narrow channels produce greater resistance to flow than wide channels of equal roughness intensity and cross-sectional area. Thus, a greater understanding of the influence of random bed elements on flow resistance in natural channels has been achieved.

A draft of a report, "Constant Resistance Coefficients for Large Bed Stream Elements," is in the process of review for publication. Termination of this outline will follow approval of the report for publication. Further work will require a new outline and objectives.

Work covering the initial investigations under this outline has been presented (ASAE National Water Resources Engineering Meeting, Memphis, Tenn., January 26-30, 1970) and an approved manuscript is pending publication.

Manuscripts:

Prepared for Review:

Overton, D.E., Judd, Harl E., and Johnson, C.W. Constant resistance coefficients for large bed element streams. Proposed for publication through the Utah Water Research Laboratory, Logan, Utah. (1971.)

Pending Publication:

Overton, D.E., and Hamon, W.R. A new resistance standard for rigid open channels. Under revision to meet acceptance for publication in ASCE, Jour. of the Hydraulics Division. (1971.)

CRIS Work Unit No.: SWC-011-fBo-1 Code No. Ida-Bo-105.4

Title: Evaluation of cover production, herbage yield, and soil conditions for different levels of management.

Location: Northwest Watershed Research Center, Boise, Idaho.

Cooperation: The Bureau of Land Management will provide partial funds and furnish public lands on which to conduct most of the investigations. The Soil Conservation Service will assist in obtaining soils data and cooperate on other aspects of the study relative to their mission.

Personnel: G.A. Schumaker and J. F. Zuzel.

Date of Initiation: February 1971

Expected Termination Date: Field work: December 1974

Interpretations and Summary: December 1975.

Objectives:

1. To determine the effect of grazing management and treatments on yield of herbage, cover production, soil moisture regimes, and soil surface conditions at selected sites.

2. To study changes in plant density and plant composition as a result of grazing management and treatments.

Need for Study, and Literature Review:

Quantitative data on herbage yield from rangelands under different levels of management are needed to guide managers of public lands in optimizing multiple use of the range. Such data are of equal importance to the Soil Conservation Service, other public bodies, and landowners. These needs require more discerning information on how vegetation and soils respond to imposed treatments, including controlled grazing. Grassland management and production factors are intimately related to other facets of the Reynolds Creek Experimental Watershed research program; particularly water use, runoff, and sediment production. Information is also needed with regard to methods

of increasing cover and to the rate of recovery of native range following intensive grazing practices. This information is needed to gain insights on the total range utilization process; that is, a stable cover that gives optimum grass production in relation to water yield with a minimum of sediment loss.

The 90-square-mile Reynolds Creek Experimental Watershed, ranging in elevation from 3600 to 7000 feet, m.s.l., offers a variety of soils and climatic zones for study. Vegetative cover is exceedingly variable in the Watershed with cover-area percentages as follows:

Percent Cover	Percent of Area
0-25	64
26-50	10
51-75	12
76-100	14

Moderate sediment yields occur from these sparsely vegetated areas. Such sites offer an opportunity for optimizing sediment reduction through management control. In the more densely vegetated areas, in the higher precipitation zones, herbage yields can be optimized while controlling erosion.

The need to learn more about vegetation influences on watersheds and to develop watershed-oriented management has been pointed out by Dunford (1).[1/] Cover and cover management play an important role in watershed hydrology and the effects of cover have been investigated by various research workers.

The effects of grazing and subsequent cover on the hydrology of salt-desert type rangeland was studied by Lusby (3) at the Badger Wash near Grand Junction, Colorado. Cover measurements taken ten years apart showed an increase in bare soil and exposed rock and a decrease in ground cover where grazing continued during the study period. Differences in runoff between the grazed and ungrazed treatments were related directly to percentage of bare soil on the watersheds under study. The greatest improvement occurred within the first three years after cattle had been excluded.

The results of Meeuwig (4) obtained from rainfall infiltrometer data emphasize the importance of vegetation and cover in maintaining infiltration capacity and soil stability on high elevation herbland on the Wasatch Front in northern Utah. Other work reported by Meeuwig (5) shows that certain soil properties can be used as predictors of

1/ Numerals in parentheses refer to corresponding items in the Literature Cited on p. 7-10.

infiltration although infiltration was not highly correlated with any one soil property. He was able to identify those site factors which are important in precipitation detention and soil erodibility. In addition, a study by Dunin (2) shows a greater infiltration and higher moisture storage from the more productive catchments near Bacchas Marsh, Victoria.

Studies concerning rangeland vegetation in the Reynolds Creek Experimental Watershed are essential to determine the effects of vegetation upon the hydrologic performance of watersheds. Most of these studies are to be made on watersheds where data will also be collected on infiltration rates, runoff and sediment yield. The watersheds sample the range of climate, geology, and soil on the 90-square-mile watershed. The watersheds range in size from 30-500 acres. Small totalizing watersheds in operation include the Northeast Summit, Sheep Creek, Reynolds Mountain, and Nancy Gulch.

Design of Experiment and Procedure to Be Followed:

Variables:

A. Variables under Investigation

1. Ecological Zones

   a. Species composition and cover
   b. Elevation
   c. Precipitation
   d. Physical characteristics of site

      (1) Soil type
      (2) Slope
      (3) Depth of topsoil or erosion

2. Seasonal Rainfall
3. Cover Management
4. Soil Moisture
5. Snow Cover

B. Variables not under Investigation

1. Plant Disease

Treatments:

A. Poor cover sites

1. Exclosure of one acre or more
2. Grazed

[illegible] infiltration was not highly correlated [illegible] and [illegible]. [illegible] important in predicting [illegible]. In addition, a study by Quinn (2) showed [illegible] moisture storage from the more productive [illegible], Nevada.

Studies concerning rangeland [illegible] management are [illegible] the hydrologic performance of [illegible] on watersheds [illegible] the range of [illegible], geology, and [illegible] watershed [illegible] in operation [illegible] Mountains, and [illegible].

[illegible]

B. Good cover sites

1. Exclosure of one acre or more with three types of brush treatment

   a. Brush removed
   b. Brush burned
   c. Brush remaining

2. Grazed

Development of Experimental Sites

A. Site Selection

1. Six to eight study sites will be selected on shallow soils where poor cover exists. Sites selected will be of varying soil types and within varying rainfall zones; therefore, sites will be different ecologically.

2. Two sites will be selected on moderately deep soils where a good grass cover exists.

3. Two sites will be selected on deep soils where a dense cover of sagebrush exists in the higher precipitation and snow accumulation zones.

B. Installation of Exclosures

At each study site an area of one acre or more will be fenced for the purpose of excluding grazing animals. An adjacent study area will be selected which will be comparable to the exclosure with respect to soil, slope, aspect, and cover. This latter site will be heavily grazed to maintain a poor cover site.

C. Installation of Soil Moisture Sites

Soil moisture access tubes will be installed at study sites for monitoring soil moisture and to determine infiltration rates by use of a rainfall simulator.

D. Vegetative Site Installations

1. At each site open to grazing six areas of 12 $ft.^2$ will be protected from grazing with cages. New sites will be established before each grazing season.

2. Within each treatment at each site two nine $ft.^2$ areas will be marked for noting changes in species composition and cover.

Description of Range Condition of Sites

Before grazing treatments are imposed on study sites, inventory data will be collected relative to erosion condition, ground cover, etc.

Data Collection Procedures

A. Dry Matter Production

1. Dry matter production will be measured twice each season. Clipping will be undertaken when early season grasses have headed and again after late season grasses have produced heads.

2. All annuals will be removed, dried and weighed. That portion of perennials which represents annual growth will be removed by clipping and weighed.

3. Production will be determined on individual species when feasible.

B. Species Composition Sites

1. Plant species and size of grass clumps will be measured twice each season on the permanent reference sites denoted for measuring species composition.

2. Each reference site will be photographed at the time of data collection in order to more carefully observe changes over the period of study.

C. Soil moisture will be measured at weekly intervals during the growing season. Additional determinations will be made following sizeable storms.

Data to be Obtained

1. Yield of dry matter.

2. Periodic inventory of plant species and cover.

3. Soil moisture content.

4. Watershed inventory of physical characteristics for each study site as developed under BLM guidelines; both at initiation and conclusion of study.

Experimental Data and Observations:

Six shallow soil sites were developed during the 1970 season. Fencing the exclosures was completed at each of these shallow-soil study sites with the exception of Upper Sheep Creek and the Nettleton private holding. All instrument sites have been selected and marked. Installation of soil moisture access tubes was started in 1970 and was more than 50 percent completed. Instrumentation for soil moisture at the shallow soil site on Upper Sheep Creek and the Nettleton private holding was incompleted. About one-half of the Nancy Gulch soil moisture sites was completed.

A deep soil site was selected on Reynolds Mountain at the 7000 feet elevation in addition to the north slope, deep soil Upper Sheep Creek site where much of the exploratory work prior to preparation of the research outline was conducted. As outlined under procedures for conducting this research, the deep soil sites will receive two types of brush treatment along with the exclusion of grazing animals. Brush removal was completed at the Reynolds Mountain site and the other brush treatment will be imposed before growth begins in 1971.

Additional soil moisture access tubes were installed at the Upper Sheep Creek site. These sites will permit soil moisture measurement to a depth of six feet. Permanent reference sites were also marked for the measurement of changes in species composition under the different treatments.

Current data consist of that from exploratory work. The effects of the treatments initiated in 1969 on the Upper Sheep Creek study area were very much in evidence during the 1970 season. On treatments where sagebrush had been removed and where the sagebrush had been sprayed, the native grasses displayed vigor and were becoming established where brush cover had previously been in existence. Grass on the ungrazed treatment where sagebrush remained also displayed some vigor owing to the absence of grazing animals. Herbage yields taken in August show the production from the four different treatments, Table 1.

TABLE 1.-- List of species clipped from Upper Sheep Creek, August 1971, and weight of dry matter removed from each treatment

2,4,5-T Sprayed ~~Brush Removed~~ No Grazing	Brush Removed No Grazing	No Treatment No Grazing	No Treatment[2/] Grazed
Species and Total Yield	Species and Total Yield	Species and Total Yield	Species and Total Yield
Stipa sp.	Stipa spp.	Bromus marginatus	Sitanion hystarex
Carex sp.	Sitanion hystrix	Stipa spp.	Poa spp.
Sitanion hystrix	Poa spp.	Sitanion hystrix	Fescus idahoensus
Poa sp.	Bromus marginatus	Agypuron trachycaulum	Stipa
Bromus marginatus	Sedge	Fescus idahoensus	Forbs
Annuals & Forbs	Annuals & Forbs	Sage[1/]	Herbaceous sage
Rabbit brush		Rabbit brush[1/]	
		Annuals & Forbs	
--Weight of Dry Matter Removed--			
773 lb./acre	793 lb./acre	267 lb./acre	

1/ Big sagebrush and rabbit brush covered 25-50 percent of the area of sites measured.

2/ Species were identified, however, animals had grazed clipping sites prior to measurement, therefore, the grazing influence was not measurable.

Data were collected from the permanent reference sites within each of the treatments. Plant species were identified and the basal cover of the grasses was measured. Where shrubs were present, measurements of aerial c over were also made. Other similar measurements have been taken from these sites annually during the study period, the progressive change in species composition and basal area can be observed.

Soil moisture measurements were taken periodically with the neutron probe from the different regimes of management during the growing season, Table 2.

The aspect of slope at the Upper Sheep Creek study site is an important factor in snow accumulation, also the type of cover can affect the depth of snow accumulation. Snow depth measurements were taken early in 1970 at random points on each of the trhee treatments, Table 3.

Comments, Interpretations and Future Plans:

A. Comments and Interpretations

The excellent herbage yields obtained from either of the brush treatments indicates that native range grasses have an ability to establish themselves once sage competition has been removed.

Current soil moisture measurements taken to a depth of three feet indicate a slightly greater depletion of store moisture for the depth of soil from the brush removed site. Further studies will indicate whether this trend continues.

Snow depth measurements indicate that less snow accumulated where sagebrush had been removed. It is very doubtful that any differences were great enough to alter the water balance on the brush removed treatment.

B. Future Plans

The development of other study sites in 1970 reached a stage where data collection can be initiated during the growing season of 1971.

TABLE 2.--Soil moisture measurements within exclosure at Upper Sheep Creek during 1970 growing seasons.

A. Treatment Within Exclosure

1. Brush Removed

Date	4-23	5-1	5-6	5-15	5-18	6-13	7-22	8-5	8-19
Depth Measured									
1	5.8	3.4	4.0	4.3	4.3	1.6	2.4	1.8	1.8
2	6.3	2.9	3.5	4.3	4.1	1.7	3.1	2.0	1.9
3	7.1	3.0		4.1	4.2	1.5	3.1	2.2	2.0
4	7.0								

2. Brush Sprayed

Date	4-23	5-1	5-6	5-15	5-18	6-16	7-22	8-5	8-19
Depth Measured									
1	6.3	5.0	5.2	4.9	4.6	2.0	3.3	1.9	2.9
2	6.3	4.7	5.5	5.2	5.2	2.2	4.3	2.9	3.1
3	6.6		4.9	4.8	4.5	2.0	4.7	3.6	2.3
4	7.3								3.5

3. No Treatment

Date	5-1	5-6	5-15	5-18	6-16	7-22	8-5	8-19
Depth Measured								
1	4.8	4.9	4.9	4.8	2.0	3.2	2.2	3.1
2	4.9	4.1	5.1	4.6	2.0	3.9	3.1	2.3
3	3.9		4.0		1.6	3.6	2.9	2.8
4								

TABLE 3--Average depth of snow on April 16, 1970, at Upper Sheep Creek exclosure.

Position on Slope	Treatment		
	Brush Removed	Brush Sprayed	No Treatment
Near Crest	8.0	11.0	11.2
Midslope	8.4	10.4	10.8
Near Base	5.4	11.0	10.0
Average	7.3	10.8	10.7

Literature Cited:

1. Dunford, E. G. 1967. Techniques in grassland watershed research, XIV. IU FRO-KONGRESS Section 11, pp. 444-462.

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5. Meeuwig, R.O. 1969. Infiltration and soil erosion on Coolwater Ridge, Idaho. USDA Forest Service Research Note INT-103.

CRIS Work Unit No. SWC-011-fBo-1 Code No. Ida-Bo-105.5

Title: Field testing and evaluating mathematical models of a two-dimensional, infiltration flow system resulting from snowmelt.

Location: Northwest Watershed Research Center, Boise, Idaho.

Personnel: D. L. Schreiber, G. R. Stephenson, C. W. Johnson, L. M. Cox, G. A. Schumaker; R. W. Jeppson (Utah State University).

Date of Initiation: July 1970

Expected Termination Date: Originally planned - December 1972
Recommendation - December 1972

Objectives:

1. To field test a numerical steady-state two-dimensional flow model and to develop and verify a transient model by use of data from a highly instrumented watershed slope.

2. To use the verified mathematical models and a sensitivity analysis to determine the influence of the various parameters (saturated conductivity, capillary pressure, bubbling pressure, and soil property coefficients) on the resulting flow patterns.

3. To use the verified mathematical models to obtain solutions for other slopes on the Reynolds Creek Experimental Watershed.

Need for Study:

In recent years intensive studies of the various subsystems of the hydrologic cycle have been conducted. Research has been designed to establish mathematical descriptions of the physical flow processes within each subsystem. The ultimate goal is a physically based, digitally simulated, hydrologic response model to describe the entire hydrologic cycle over any watershed.

Any comprehensive study of watershed precipitation-runoff relationships must not neglect the flow system that occurs in the soil mantle. Input to such a flow system is generally provided by infiltration of snowmelt or rainfall through the soil surface. Recent studies have demonstrated that the infiltration characteristics of the soils and the partially saturated flow system in the soil mantle are the result of several interacting fundamental soil properties. The occurrence and magnitude of overland flow, quantities of interflow and baseflow, and recharge to the groundwater aquifer are all dependent upon the soil properties. If soil mantle flow systems can be described adequately, progress towards the goal of simulating the hydrologic cycle will be achieved.

This study should provide an important link for any comprehensive runoff prediction model that includes snowmelt on a watershed. Snowmelt is an important contributor to spring and early summer runoff from many watersheds in the Northwestern United States. Ultimately, this study will be used to develop more accurate methodology for predicting surface and subsurface flow from a watershed. Information concerning the flow system resulting from snowmelt infiltration is essential if Northwestern lands are to be managed for optimum multiple use.

Design of Experiment and Procedure to be Followed:

Steady-state mathematical solutions for a two-dimensional flow system resulting from infiltration on a watershed slope were analyzed initially in a 1969 exploratory study and in project report PRWG-59c-1, "Numerical Solution of the Steady-State Two-Dimensional Flow System Resulting from Infiltration on a Watershed," by R. W. Jeppson, Utah Water Research Laboratory, Utah State University. It was found that the partial differential equation boundary value problems based on basic soil properties were within reach of solution capabilities.

Since a steady-state model of a watershed cannot provide complete predictive information for the naturally unsteady watershed flow system, effort will also be devoted toward the development of a comparable transient mathematical model for the partially saturated flow system of a watershed slope. This transient model would include a source of moisture such as snowmelt or rain, evapotranspiration and deep percolation all incorporated as boundary condition in the partial differential equation initial-boundary value problem.

In developing the model for the transient flow system and in testing its solution capabilities, the solution from the steady-state model will act as a "bench mark" toward which the transient solution should approach in an asymptotic manner at longer time intervals. Consequently, the steady state solution results will also act as a check on the accuracy of transient solutions from more sophisticated mathematical models.

In order to evaluate the effects of soil parameters, to establish the actual flow pattern, and to demonstrate the usefulness of the mathematical solution results, a watershed profile was selected and heavily instrumented. The northeast slope of the Upper Sheep Creek Watershed W-17, a subbasin of the Reynolds Creek Experimental Watershed, was selected. The instrumentation sites are shown in Figure 1[1/], a contour map of the Upper Sheep Creek Watersheds, and in Figure 2, a profile cross section of the slope.

The instrumentation from which data were obtained during the water year 1969-70 includes: (1) seven single probe and two dual probe sites for measuring soil moisture with a neutron probe, (2) two single piezometers at sites P-1 and P-2 for measuring the potential surface of the saturated region, (3) three sites containing batteries of tensiometers at various depths for measuring soil

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1/ All figures pertaining to this Research Outline are located in order following page 8-10.

moisture tension beneath the snowpack, and (4) two identical drop-box weirs with cutoff walls for measuring stream-channel flow upstream and downstream from the instrumented slope. At the beginning of water year 1970-71 nine more piezometers were installed. Two of the additional piezometers were installed at site P-1 to provide a battery of three piezometers at various depths. The single piezometer that was located at site P-2 was discontinued in place of a battery of four new piezometers at various depths. A battery of three piezometers was also installed at a new site, P-3, in the middle of the slope.

A seismic survey was conducted late in the water year 1969-70 on the instrumented slope. This survey was necessary to complement and complete the profile cross-section information obtained from driller's logs of the soil moisture and piezometer sites.

Experimental Data and Observations:

Moisture content data for the soil profiles at the soil moisture and dual probe sites were obtained on a weekly basis throughout the year with a neutron probe. During the snowmelt season soil moisture data were obtained twice weekly. Gravimetric samples were taken occasionally to spot check the neutron-probe soil-moisture data and to determine bulk density, porosity, and saturated conductivity. Representative data for soil moisture, bulk density, porosity, and saturated conductivity are listed in Table 1. Representative soil moisture content profiles obtained from the neutron probe data at sites SM-1, DP-2, and SM-5 are illustrated in Figures 3, 4, and 5, respectively.

The two single piezometers from which data were collected during water year 1969-70 were located at site P-1, close to the stream channel, and at site P-2, on the upper portion of the slope just below the usual snowpack area (see Figures 1 and 2). These piezometers were used to determine roughly the potential surface of the saturated region. The hydrograph obtained during the snowmelt season from the lower piezometer P-1 is illustrated in Figure 6.

Three multiple-cell tensiometers were located in the soil under the snowpack to measure capillary pressures at various depths in the soil. This data is listed in Table 2.

Periodic surveys were made during the snowmelt season to obtain the location, volume. and water equivalent of the snowpack. The average density of the snowpack remained essentially constant (0.49-0.55) during the snowmelt season. Figure 7 illustrates the changes in a typical cross-sectional area of the snowpack during the winter and spring of 1970.

The snowmelt data were analyzed by two methods. One method was used to indicate only the total volume of water that melted from the snowpack each day. The second method was used to derive a soil surface intake rate by accounting for the decreasing ground surface area beneath the snowpack. Daily melt rates from the cooperative ARS-SCS snow pillow site at Reynolds

TABLE 1.--Soils data from the north slope of Upper Sheep Creek Watershed W-17.

Depth, feet	Water Content, % volume								Average Bulk Density,[2/] gm/cm[3]	Average Porosity,[3/] %	Average Saturated Conductivity,[4/] cm/min
	Neutron Probe				Gravimetric Samples[1/]						
	Site SM4		Site SM5		9-2-70		9-10-70				
	9-2-70	9-9-70	9-2-70	9-9-70	Actual	Average	Actual	Average			
0.0-0.5					22.5		17.8		.94	64.6	.0229
0.5-1.0	11.6	13.8	12.4	14.9	15.0	15.2	16.2	16.9	.85	66.9	.0441
1.0-1.5					15.5		17.6		.90	66.2	.0396
1.5-2.0	13.6	15.5	14.4	15.5	18.0	17.8	21.8	22.6	.91	66.0	.0540
2.0-2.5					17.7		23.5		.84	68.3	.0483
2.5-3.0	16.2	16.1	16.5	19.0	19.2	19.2	25.7	24.8	.89	66.4	.0485
3.0-3.5					19.1		23.9		.89	66.4	.0619
3.5-4.0	17.9	18.4	24.1	25.8	21.9[5/]	....	27.8[5/]	....	...	....	.....

1/ Samples were taken from a pit located approximately 25 feet west of piezometer battery P2. Dry-weight moisture contents were determined and converted to volume basis.

2/ Samples of constant volume (136.6 cm^3) were taken from the pit mentioned in footnote 1/ with a Soiltest core sampler.

3/ Values were computed using a value of 2.65 for real specific gravity.

4/ Values were determined using 25-gram samples in constant-head permermeters.

5/ Value was left on dry-weight basis, since bulk density value was missing.

TABLE 2.--Soil moisture tension data from the north slope of Upper Sheep Creek Watershed W-17.

1970 Date	Military Time	Tension in Inches of Water below Tensiometer Depth[1] Site T-1 Tensiometer Depth[2] 6.00	18.25	2.75	Site T-3 Tensiometer Depth[2] 7.00	15.25	19.25
5-22	0905	......	......	6.77	0.14[3]	14.14	15.64
	1055	......	......	9.90	+12.35	+ 9.48	16.97
	1250	......	......	21.77	+11.23	+ 9.23	16.02
5-25	0930	......	......	20.27	24.27	20.52	22.67
	1110	......	......	20.67	25.72	21.08	23.17
	1620	1.26	+23.99	21.90	31.08	23.08	24.83
5-26	1015	12.39	+11.74	27.15	42.90	27.52	28.77
	1100	+ 0.24	+ 9.80	27.27	43.52	27.52	28.77
	1205	+ 6.24	+ 8.49	27.65	44.52	27.77	28.77
	1300	+24.24	+ 7.61	27.83	45.27	27.77	28.77
	1400	+42.24	+ 6.43	28.02	46.52	28.02	28.77
	1500	+42.24	+ 5.49	28.40	47.40	28.27	27.77
	1600	+42.24	+ 4.70	28.40	48.27	28.52	27.65
	1700	+42.24	+ 4.11	28.52	49.15	28.77	+10.48
5-27	1445	+39.99	+20.38	31.02	52.02	31.90	+18.73
5-28	1310	+40.49	......	34.02	......	34.77	+22.23
	1445	+40.37	+54.24	34.33	63.08	34.77	+21.29
5-30	1650	+38.74	+53.24	40.57	+ 9.48	+10.48	+20.98
6-4	1230	+38.76	+50.17	47.93	12.24	42.99	+16.69
6-8	1345	+35.28	+49.45	58.25	15.48	0.51	+10.45
6-9	1200	+24.74	+45.49	58.52	16.52	+ 3.86	+ 7.33
6-10	1200	+33.84	+41.99	57.77	17.12	+ 3.86	+ 7.33

1/ Tensiometers at Site T-2 did not function properly.

2/ Depth is in inches below ground surface.

3/ Plus (+) sign indicates positive pressure head in inches above tensiometer position.

Mountain, 4.0 miles southwest of the snowpack on the north slope of Upper Sheep Creek Watershed W-17, were used as a guide in determining daily melt rates at the latter site. The Reynolds Mountain snow pillow site is comparable to the snowdrift area on the north slope of Upper Sheep Creek. Exposure is approximately the same, and the elevation, 6700 feet, is only a difference of 500 feet. Snow melt and rainfall data from the Reynolds Mountain snow pillow site and rainfall data from the Lower Sheep Creek Weather Station (1.5 miles northwest of the north slope of Upper Sheep Creek and at elevation 5410) and from the Black Mountain rain gage (0.7 miles northeast of the north slope of Upper Sheep Creek and at elevation 6610) are listed in Table 3. Results of the two methods of analyzing the snowmelt data are illustrated in Figure 8.

Stream-channel flow is measured upstream and downstream from the instrumented slope by two identical drop-box weirs with cutoff walls. No overland flow or surface runoff from the slope was observed during the snowmelt period. Channel flow is attributed to subsurface flow from snowmelt infiltration with subsequent seepage into the stream channel. The difference between the hydrographs from the two weirs is illustrated in Figure 6 and gives an indication of the snowmelt hydrograph after it is attenuated by flowing downslope through the soil mantle system.

Comments, Interpretations, and Future Plans:

A comparison of Figures 6 and 8 indicates that equilibrium or steady-state conditions have not been fully achieved. The snowmelt hydrograph peak precedes the lower piezometer hydrograph peak by two weeks, and the latter precedes the channel-runoff peak by five days.

The adequacy of the steady-state mathematical model developed by Jeppson for this study in defining variations in hydraulic conductivity or other soil parameters from an unsteady field situation needs further study. In brief, more field measurements are needed. However, the model does indicate what types of additional observations should be obtained.

At the time the computer problems were formulated, not all of the data needed to completely define the field flow situation were available. For example, the two initial batteries of tensiometers at sites T-1 and T-2 were located during the autumn of 1969 just below the expected extent of the 1969-70 snowpack accumulation. However, the snowpack did not extend downslope as far as had been anticipated. An additional battery of tensiometers were installed at site T-3 beneath the snowpack during the spring of 1970, but prior to the heavy snowmelt period. Furthermore, measurements to determine the lateral and vertical variations of saturated hydraulic conductivity were not complete. In fact, the work plan called for using the steady-state model to indicate what field measurements would be most useful. Consequently, judgment was used in estimating some of the parameter values needed to define the computer problems. The other parameter values were varied in a systematic fashion to bring computer solutions to closer agreement with certain observed features of the actual flow system.

TABLE 3.--Comparable snowmelt and rainfall data.

May 1970 Date	Snowmelt at Reynolds Mountain Snow Pillow Site[1/], Inches	Rainfall at Reynolds Mountain Snow Pillow Site[1/], Inches	Rainfall at Lower Sheep Creek Weather Station[2/], Inches	Rainfall at Black Mountain Rain Gage[3/], Inches
1	0.10	....	....	....
2	0.55	....	....	....
3	0.84	....	....	....
4	0.90	....	....	....
5	0.74	....	....	....
6	0.69	0.07	0.04	0.03
7	0.66	....	....	....
8	0.92	0.43	0.09	0.13
9	0.39	0.25	0.09	0.08
10	0.13	0.29	0.12	0.24
11	0.02	0.05	....	....
12	0.01	0.11	0.02	0.03
13	0.00	0.09	0.03	0.02
14	0.03	....	....	0.04
15	0.89	....	....	....
16	1.55	....	....	....
17	1.27	....	....	....
18	1.31	....	....	....
19	0.99	....	....	0.04
20	0.52	0.19	0.11	0.08
21	1.50	....	....	0.02
22	0.63	0.03	0.13	....
23	1.49	0.38	0.34	0.51
24	2.31	....	....	0.01
25	2.60	....	....	....
26	2.55	0.07	0.03	0.06
27	1.29	....	....	0.02
28	0.49	....	....	....
29	0.01	....	....	....

1/ Gage 176407 located at elevation 6780 and 4.0 miles southwest of the north slope of Upper Sheep Creek Watershed W-17.

2/ Gage 127407 located at elevation 5410 and 1.5 miles northwest of the north slope of Upper Sheep Creek Watershed W-17.

3/ Gage 128487 located at elevation 6610 and 0.7 miles northeast of the north slope of Upper Sheep Creek Watershed W-17.

On the basis of the soil tension data (Table 2) and the soil moisture measurements (Figures 3, 4, and 5), the capillary tensions were specified in the computer problems as either 0.5 or 1.0 feet of water. Drillers' logs indicated that soil material obtained during the installation of the piezometers and soil moisture tubes contained an increasing amount of fines with depth. Consequently, a function allowing decreasing values of hydraulic conductivity with depth below the ground surface was used in practically all of the computer solutions.

The values for the boundary coordinates in the computer solutions were selected upon examination of the field data. Piezometer data were not adequate to define the position of the water table throughout the watershed slope for a steady-state flow system; however, the saturation data obtained from soil moisture measurements suggested that the water table created by snowmelt would be a relatively small distance below the ground surface. Therefore, boundary coordinates from the base of the snowpack to the stream channel were selected to give a water table at a depth of one foot or less. Boundary coordinates for the impervious layer were selected to give depths to the restrictive layer as suggested by the drillers' logs and as shown in Figure 2.

It is not practical to include all of the computer solution results in this report. Flow nets for four solutions are presented in Figures 9, 10, 11, and 12, to facilitate the explanation of factors that appear to influence the downslope flow within a watershed profile. Every other streamline and equipotential line that was computed is plotted on these flow nets. The dashed line separates the saturated and the partially saturated flow regions (flow above the dashed line is partially saturated, whereas, the flow below the dashed line is saturated).

The first two flow nets, Figure 9 and 10, present the solution to problems with all parameter specifications identical, except for the variation in the saturated hydraulic conductivity, K_o. Furthermore, in both problem specifications the change in saturated hydraulic conductivity with respect to the stream function is identical such that K_o at the ground surface equals 1.75 plus K_o just above the impervious layer, and such that K_o varies linearly between the two surfaces.

In the problem illustrated in Figure 9, no variation in the hydraulic conductivity was specified with respect to the potential function. In essence, the soil at the bottom of the slope was assumed to have similar hydraulic properties to the soil at the top of the slope. Since the shape of the resulting ground surface profile illustrated in Figure 9 is steeper near the channel and flatter near the top than that of the actual watershed as shown in Figure 2, some parameter specification or combination of specifications needs to be modified.

While a number of the parameters used to specify the problem may be changed to allow closer agreement between the computer solution and the actual profile shape, the most logical change seems to be to vary the saturated hydraulic conductivity, K_o, such that its value is greater at the bottom than near the top of the slope.

Solution to several problems (not illustrated in this report) were obtained in which K_o was specified to vary linearly with the potential function and to be approximately twice as great at the bottom as it was at the top of the slope. With only linear variations in K_o and without variations in the anisotropy parameter or changes in the boundary coordinates, it soon became apparent that complete agreement between computed and actual profiles could not be achieved.

Regions of nonconformity, except near the stream channel, were eliminated systematically by superimposing positive and negative sine curves on a decreasing linear function of K_o with potential function. A flow net for such a formulation is illustrated in Figure 10. These results indicate that the actual saturated hydraulic conductivity varies with distance up the slope from the channel bottom. More precisely, K_o decreases from the streambed up the slope for about one-third the distance, then just below the dual probe site DP-2, it increases sharply. K_o then decreases again until near the top of the slope, where it increases again.

The sharp increase in saturated hydraulic conductivity required by the results of the solution in the vicinity of the dual probe site DP-2 may result from the actual decrease in surface soil depth at this location. Furthermore, saturated hydraulic conductivity data obtained in the laboratory support this hypothesis. Values of K_o were obtained from disturbed soil samples taken from three pits spaced along the slope. Samples taken from a pit near site DP-2 yielded K_o values that were approximately twice as large as K_o values obtained for the soils in pits located near the piezometer sites P-1 and P-2.

It is noteworthy that other parameter specifications and variations could have been used to bring solution results in agreement with the actual case. Agreement could probably have been achieved by varying the anisotropy parameter in the upslope direction, or by specifying different boundary coordinates.

Different boundary coordinates were specified for other solutions, in which the water table was maintained within a depth of one foot from the ground surface, and in which the capillary tension head in the soil beneath the snowpack was maintained at one foot of water. The flow net that is illustrated in Figure 11 resulted from such a solution. In this and other such solutions not included here, only linear decreases of K_o with potential function were defined. Of these solutions the profile shown in Figure 11 corresponds best to the actual profile. However, this profile does rise above the actual profile just upslope from the dual probe site DP-2, at the position where the restrictive layer reduces the depth of the surface soil. Again with these coordinates, the actual profile cannot be duplicated unless K_o is sharply increased in the vicinity of DP-2 while the anisotropy parameter is maintained constant, or vice versa, or a combination of the two parameters is taken.

The solution, illustrated in Figure 12 used still other boundary coordinates in its specifications. Here it was assumed that a slightly larger increase

in the saturated hydraulic conductivity with stream function exists than in previous solutions, and that K_o does not vary with potential function. Saturated hydraulic conductivity in the horizontal direction was assumed to be twice as great as in the vertical direction. Therefore, this solution illustrates the shape that the watershed profile would have under steady-state flow conditions with the depths of soil shown, with the entire water table close to the ground surface, and with saturated hydraulic conductivity characteristics the same at the top as at the bottom of the slope. The computed profile is much steeper in the areas of shallower soil than is the actual watershed. In these shallow soil regions either the water must emerge from the surface or K_o must be greater than in the remaining profile. Should the water emerge from the surface, it would tend to make this area more susceptible to erosion, and thus provide a natural mechanism for further reduction in the depth of soil capable of transmitting moisture.

Future plans include the development and verification (with field data) of a numerical, transient, two-dimensional flow model. R. W. Jeppson, Utah Water Research Laboratory, will develop the model, and the Northwest Watershed Research Center staff will obtain the necessary data for verification from the 1970-71 water year. To meet these needs, the new piezometer batteries mentioned in an earlier section of this report were installed. Tensiometer batteries will be installed at the base of the snowpack prior to the snowmelt season. Since it was demonstrated last year that good tension data are difficult to attain, an effort will be made to modify the tensiometers. An ideal situation would include continuous recorders and no hydraulic lines on the tensiometers. The recording rain gage 138031 that is located very close to the study area (Figure 1) will be modified so that it will provide reliable data (no data were available for water year 1969-70). Further geologic and hydrologic investigations will be conducted to determine if all the water from the large snowpack on Upper Sheep Creek Watershed W-16 flows through the drop-box weir W-16 before entering the stream channel of Upper Sheep Creek Watershed W-17.

A manuscript in preparation since last year's report is the following:

Jeppson, R. W., Schreiber, D. L., Stephenson, G. R., Johnson, C. W., Cox, L. M., and Schumaker, G. A. 1971. Solution of a watershed flow system resulting from snowmelt with verification by field data. Abstract accepted for presentation at the 1971 Annual National Summer Meeting of ASAE, June 27-30, Pullman, Washington. Manuscript to be submitted to SWC for approval to publish in the Transactions of the ASAE.

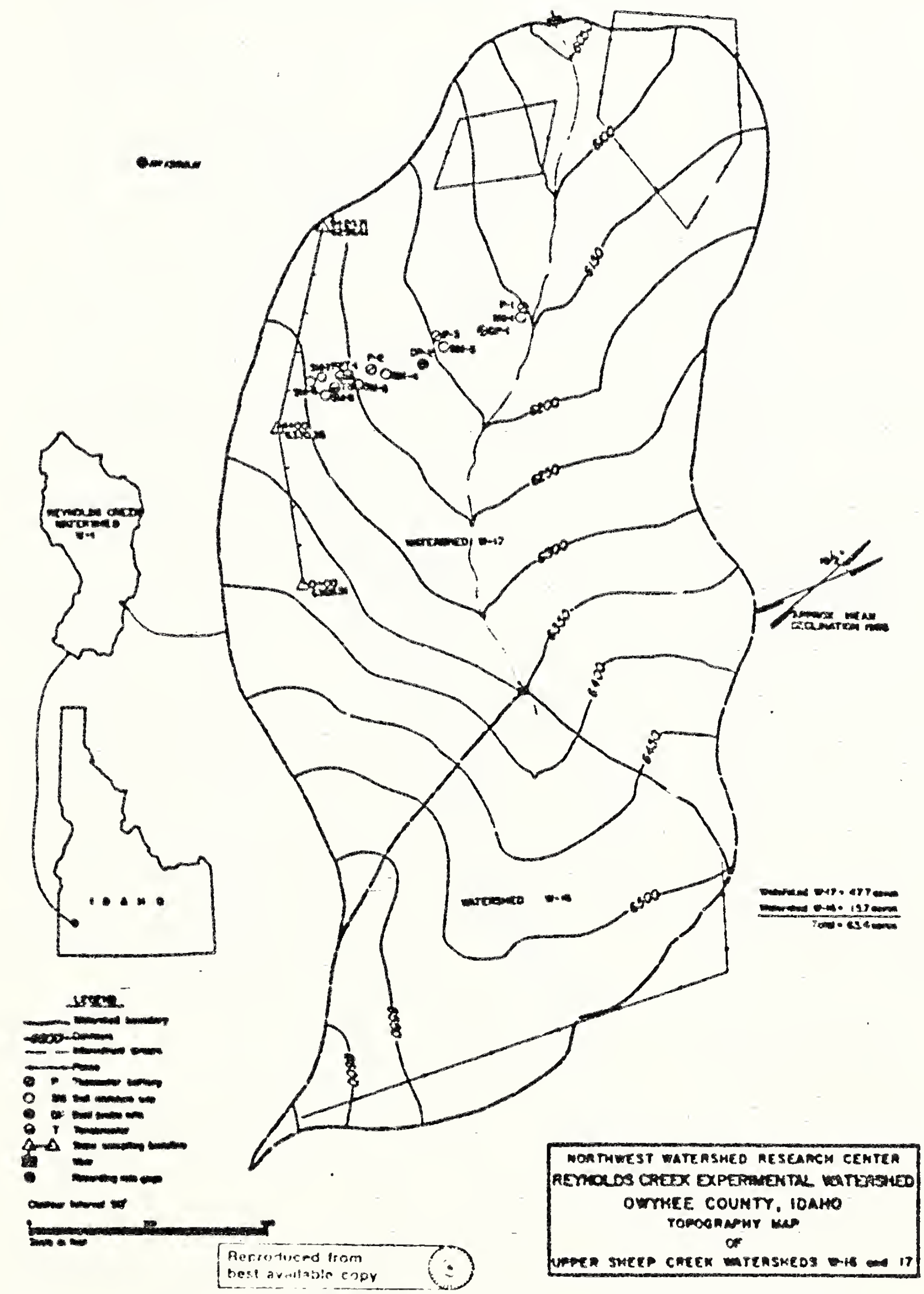

Figure 1. Instrumentation and topography map of Upper Sheep Creek Watersheds W-16 and W-17.

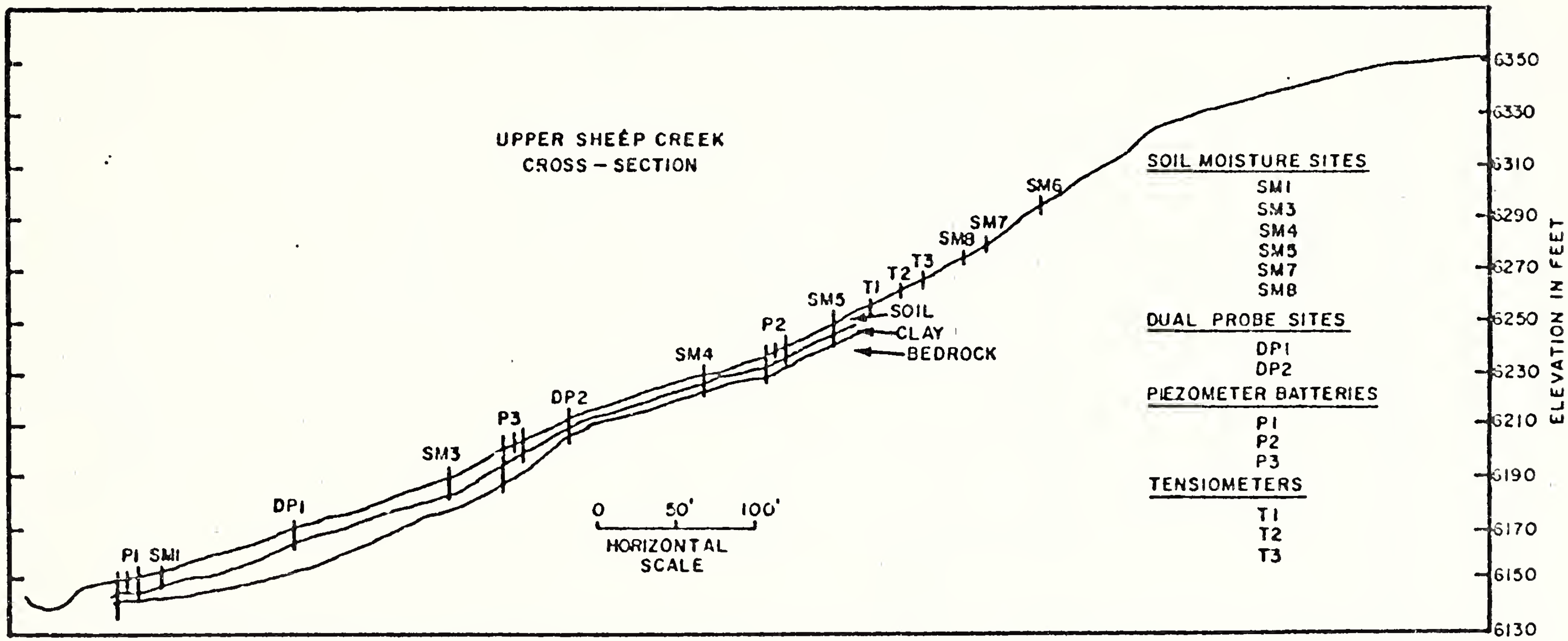

Figure 2. Profile cross section and instrumentation of North Slope Upper Sheep Creek Watershed W-17.

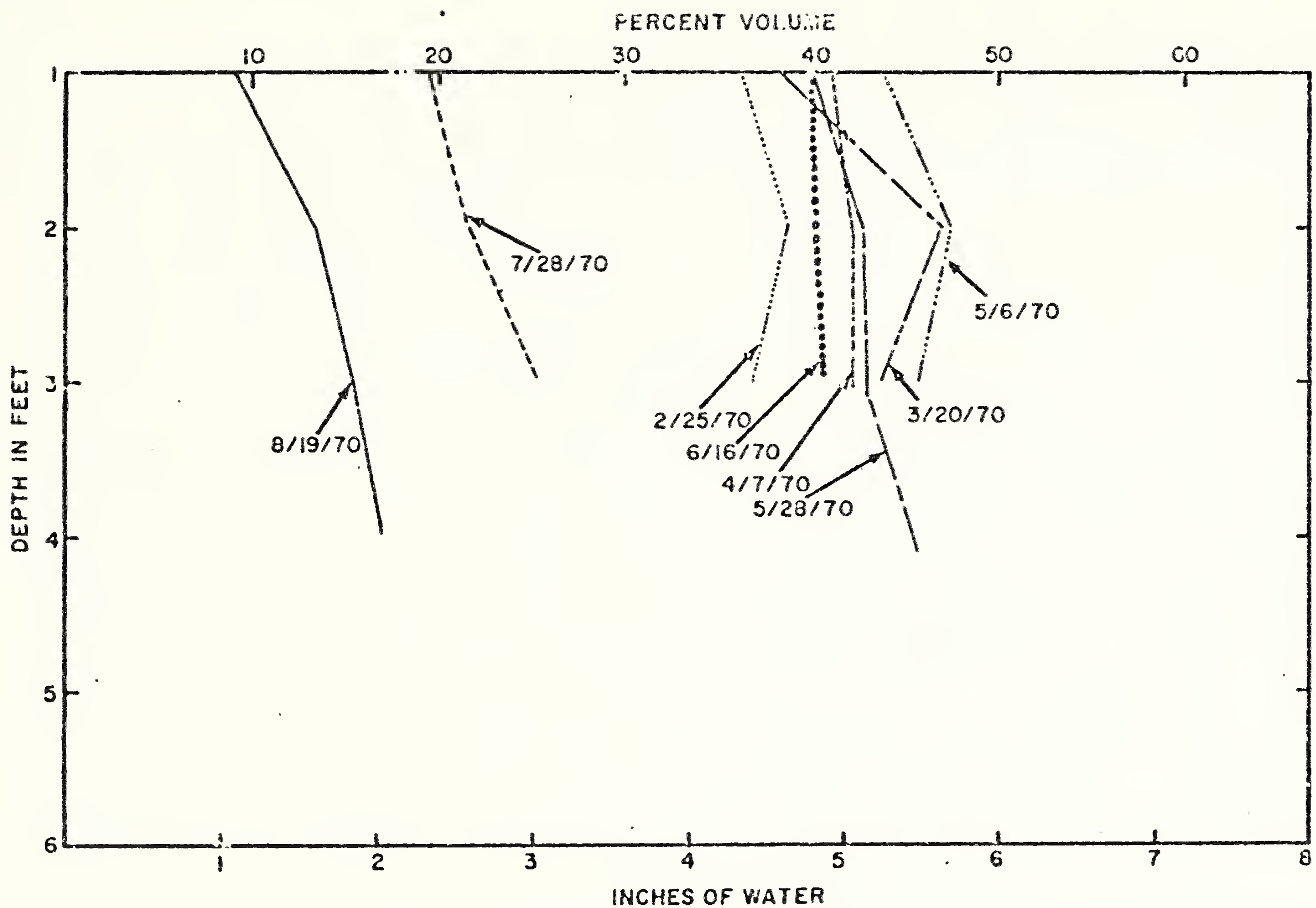

Figure 3. Soil moisture content profiles obtained with neutron probe at Site SM-1, North Slope Upper Sheep Creek Watershed W-17.

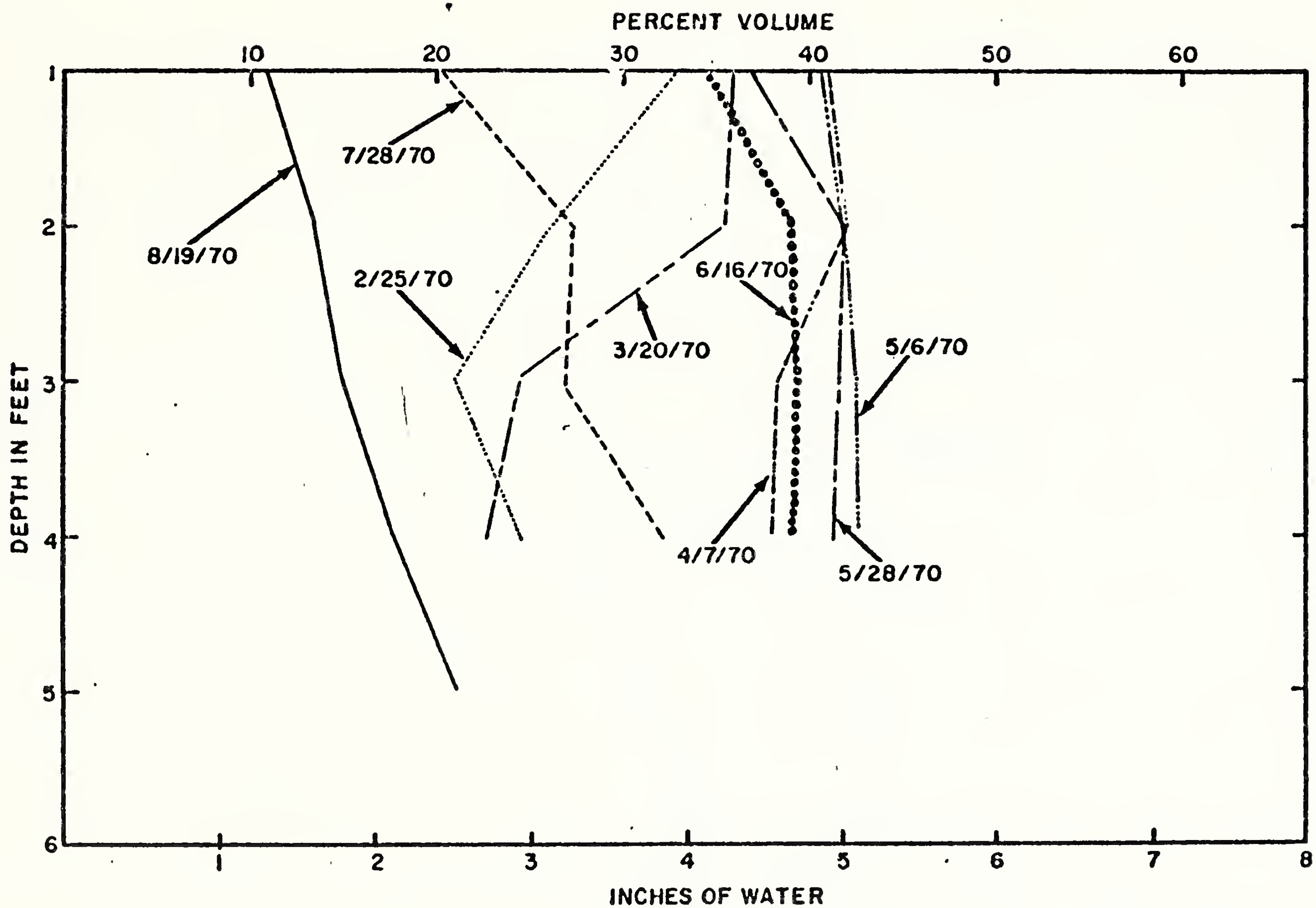

Figure 4. Soil moisture content profiles obtained with neutron probe at Site DP-2, North Slope Upper Sheep Creek Watershed W-17.

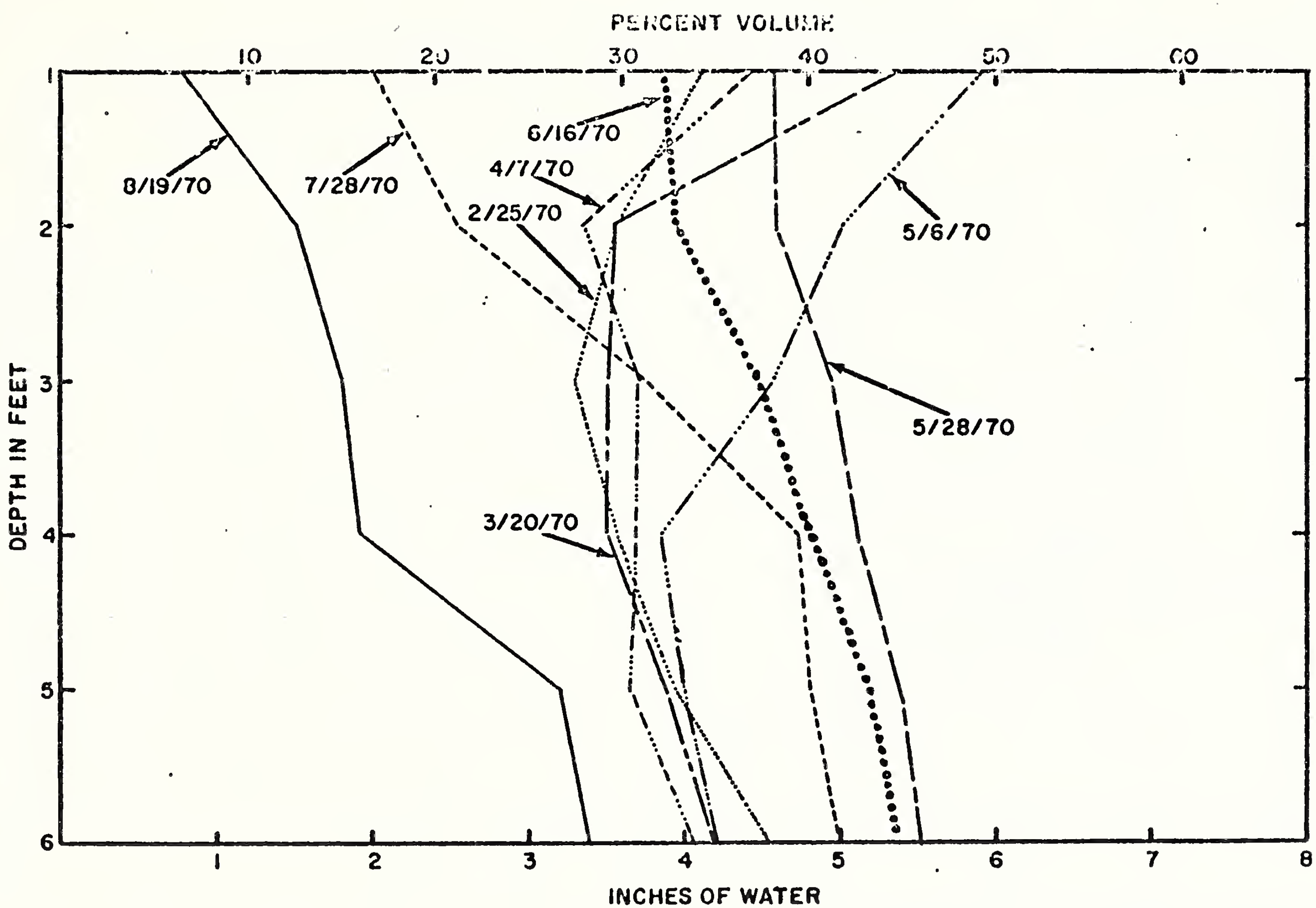

Figure 5. Soil moisture content profiles obtained with neutron probe at Site SM-5, North Slope Upper Sheep Creek Watershed W-17.

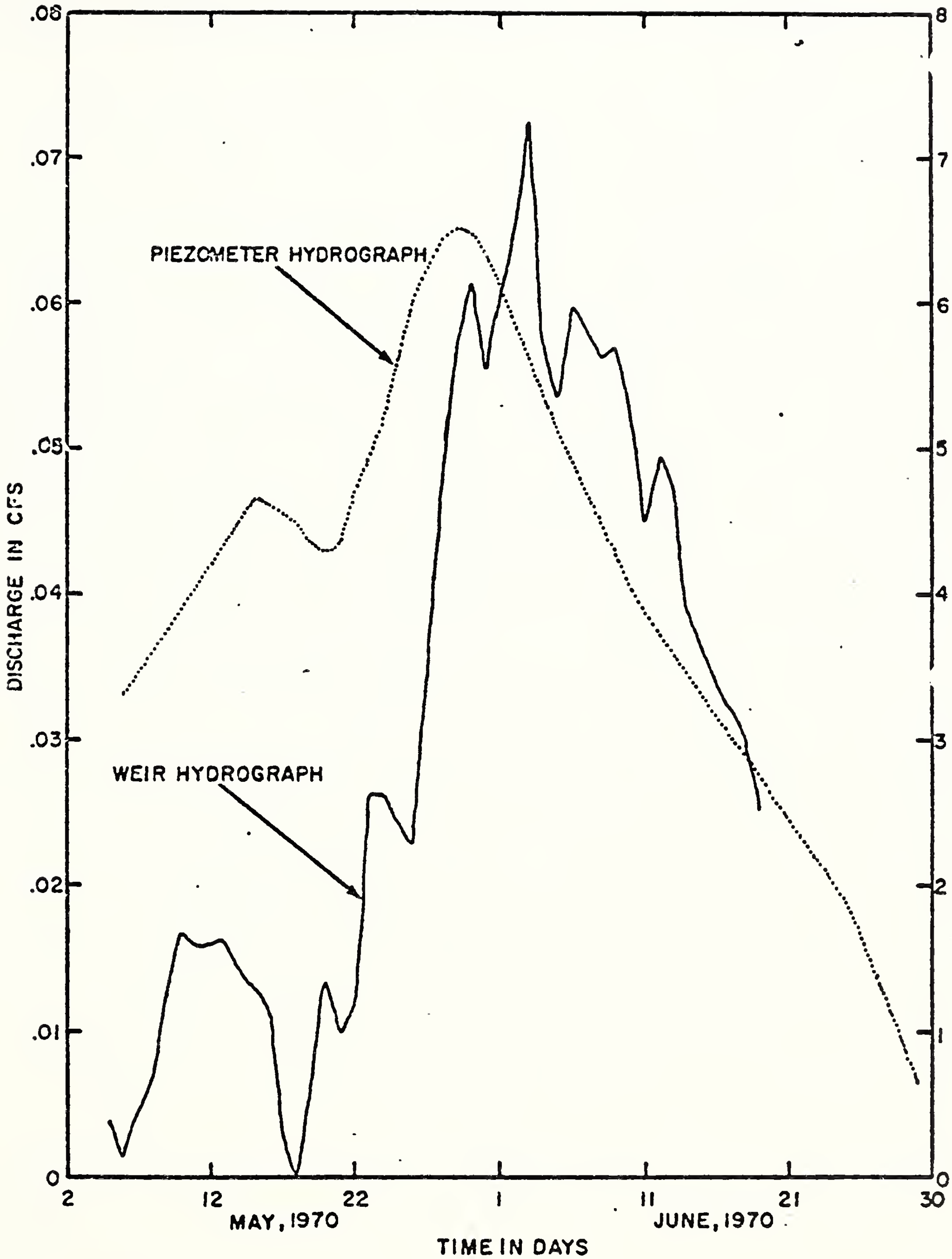

Figure 6. Hydrographs for piezometer P-1 and stream channel, North Slope Upper Sheep Creek Watershed W-17.

Figure 9. Hydrographs for piezometer [illegible]
North Slope [illegible]

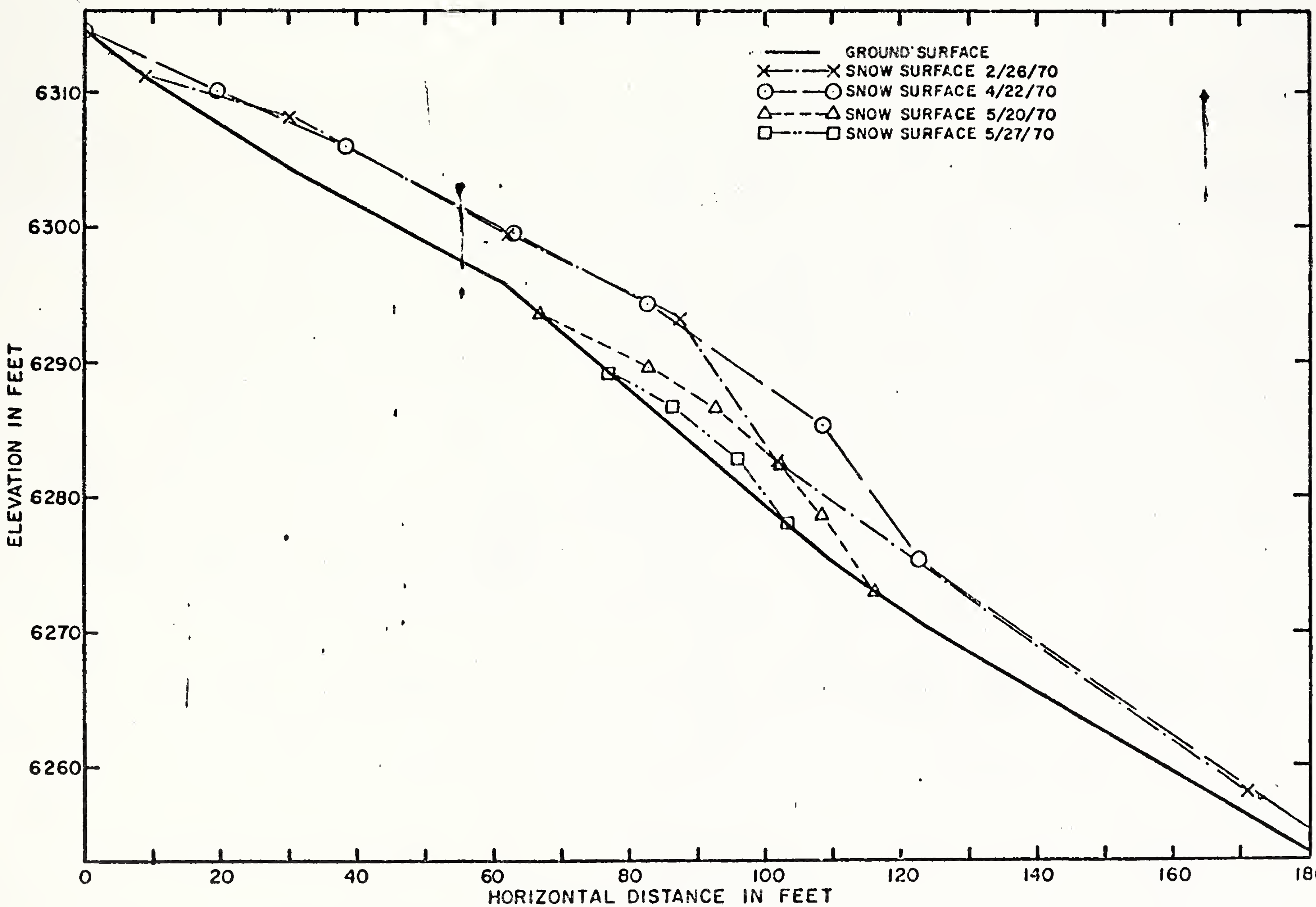

Figure 7. Changes in snowpack cross-sectional area at station 5 + 00, North Slope Upper Sheep Creek Watershed W-17.

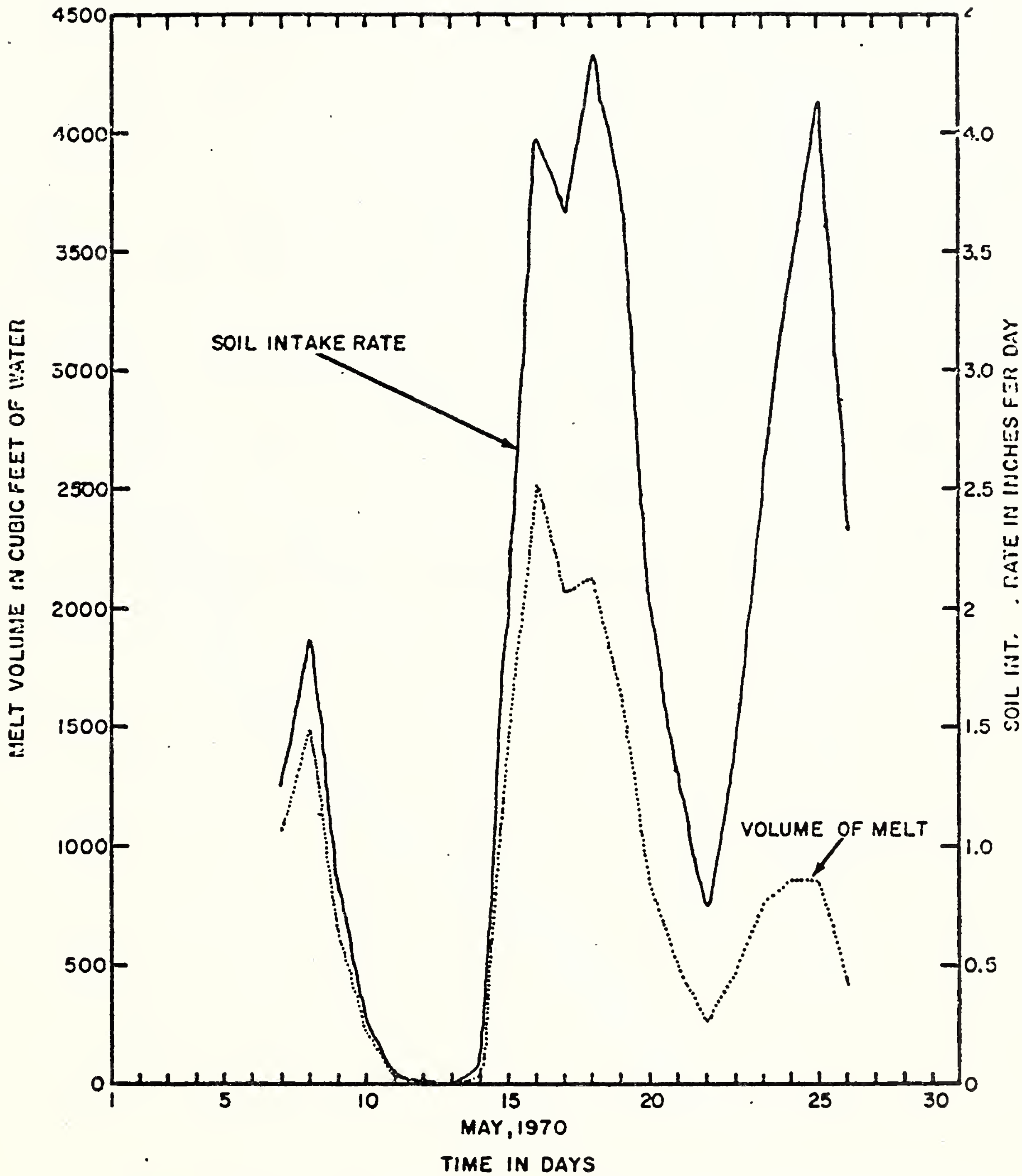

Figure 8. Hydrographs of snowmelt, North Slope Upper Sheep Creek Watershed W-17.

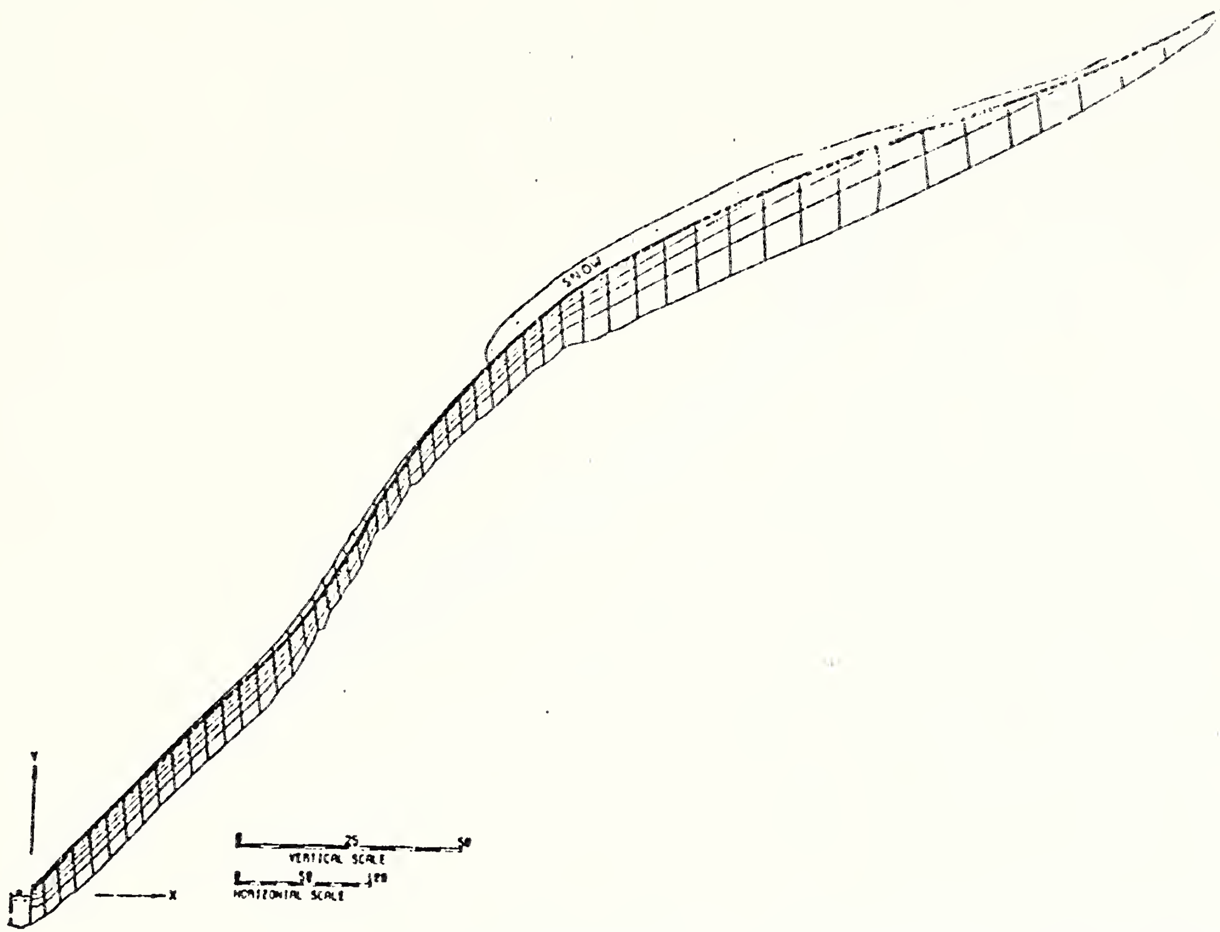

Figure 9. Computed flow net resulting from a linear variation of saturated hydraulic conductivity with stream function and no variation with potential function.

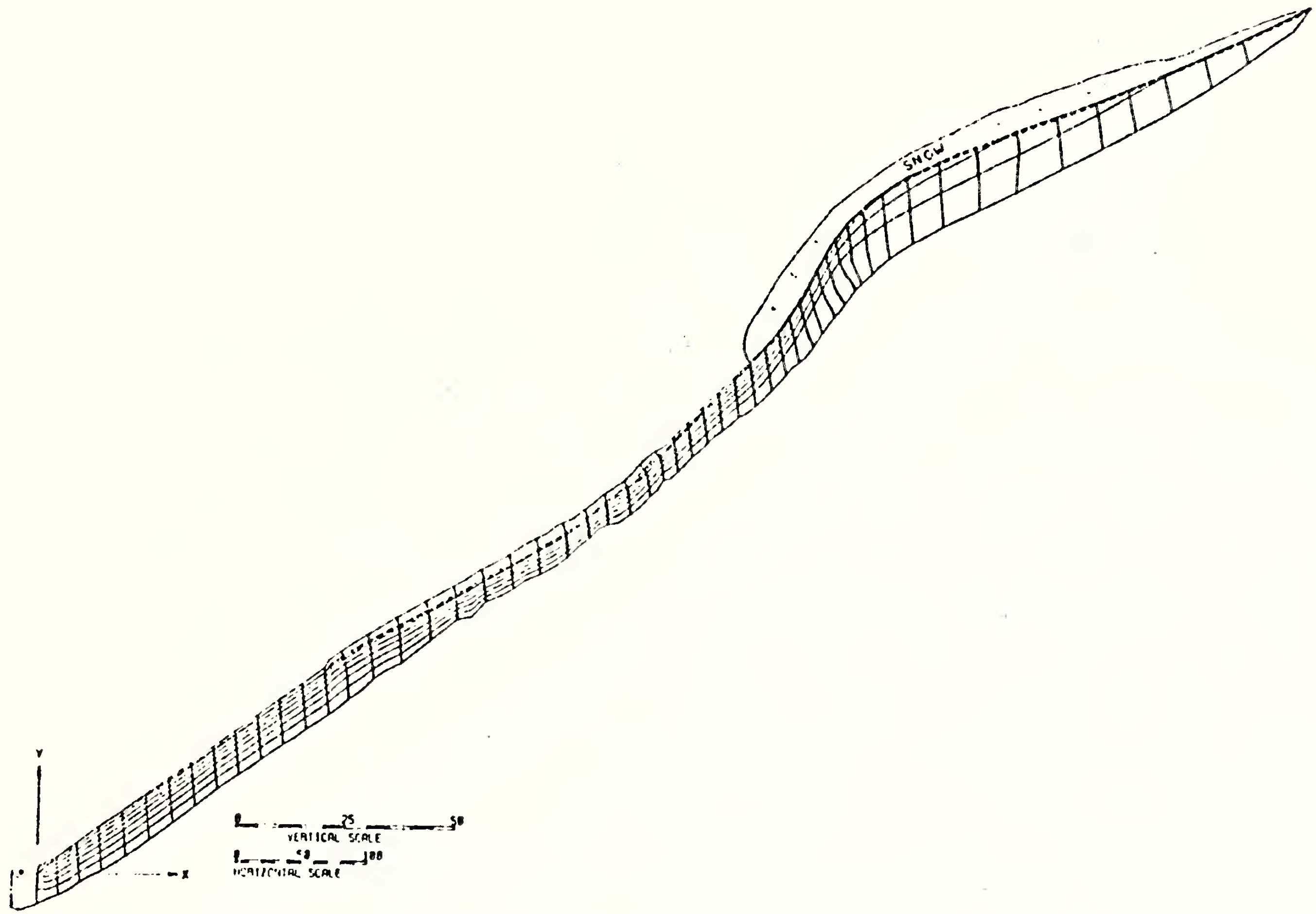

Figure 10. Computed flow net resulting from a linear variation of saturated hydraulic conductivity with stream function and a nonlinear variation (positive and negative sine curves superimposed on a decreasing linear function) with potential function.

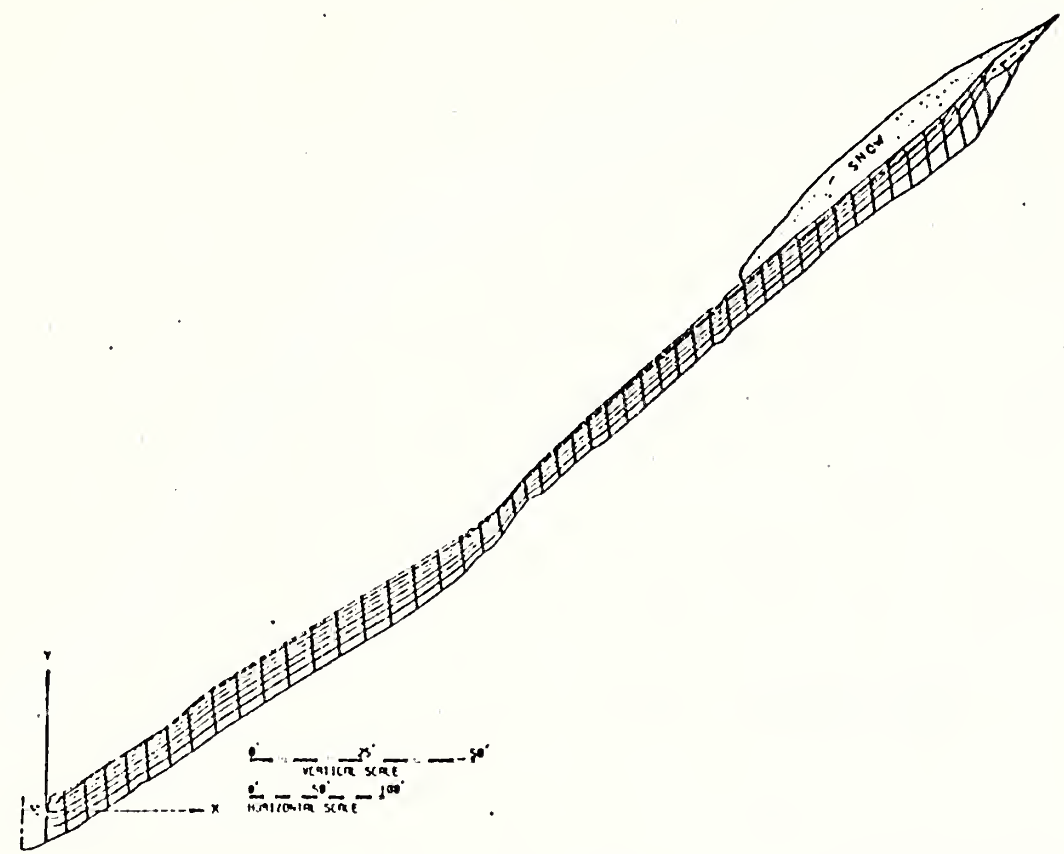

Figure 11. Computed flow net resulting from linear variations of saturated hydraulic conductivity with stream function and with potential function.

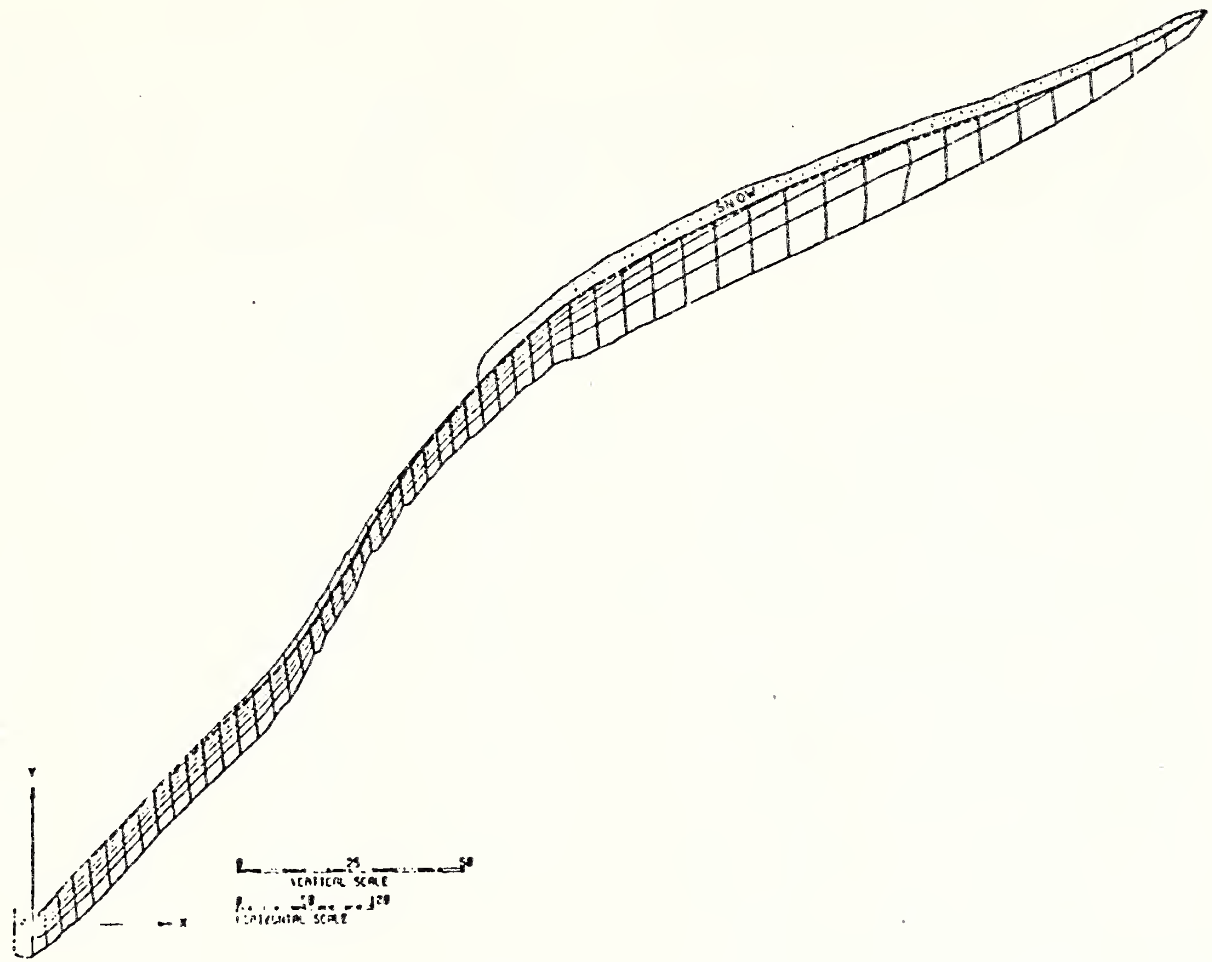

Figure 12. Computed flow net resulting from different linear variations of saturated hydraulic conductivity with stream function and with potential function.

CRIS Work Unit No. SWC-011-fBo-1 Code No. Ida-Bo-105.6

Title: Developing, testing, and evaluating an analytical infiltration model.

Location: Northwest Watershed Research Center, Boise, Idaho.

Cooperation: The Utah State University Water Research Laboratory will cooperate in the analytical phases of this study. The Oregon State University Agricultural Engineering Department will cooperate in assessing soil properties and in laboratory and in field testing. The Bureau of Land Management, USDI, will contribute support and participate in pursuit of the study.

Personnel: D. L. Schreiber, W. R. Hamon, and G. A. Schumaker (ARS-SWC); R. W. Jeppson (Utah State University); and R. H. Brooks and E. N. Biggs (Oregon State University).

Date of Initiation: February 1971

Expected Termination Date: Field Work: November 1974. Laboratory: September 1972. Interpretation and Summary: December 1974.

Objectives:

1. To develop or adapt mathematical models in the form of partial differential equations to describe steady-state and transient one-dimensional and three-dimensional axisymmetric flow through partially saturated soils.

2. To determine quantitative means by use of the mathematical models to adjust for lateral "spreading effect" of moisture movement from a circular rainfall simulator under various soil types and conditions.

3. To test and refine the mathematical models by comparing results with laboratory and field determinations of infiltration and to establish the relative influence of the several interacting physical processes on infiltration.

4. To determine the parameters in the saturation-pressure relationship (moisture characteristic) and saturated conductivity by the use of parameter optimization in conjunction with the mathematical models and infiltration data.

5. To determine the potential quantity of water retainable by various soil-vegetation complexes that is independent of infiltration for different initial soil moisture levels.

Need for Study:

Infiltration of water into soil profiles is the critical hydrologic component in watershed management, overland flow prediction, sediment generation, natural and artificial ground-water recharge, and irrigation. With increased public interest in the management of land and water resources, better analyses and predictive methods for describing infiltration and flow in porous media are needed.

This study should provide an important link for the development of a comprehensive hydrologic response model. More accurate information concerning the flow system resulting from infiltration is essential if agricultural lands are to be managed for optimum multiple use.

Much data have been collected around the country in past years using small infiltrometers on many different soil types. This study should provide a quantitative means to adjust the data for the lateral spreading effect of the water beyond the boundary of the ring. Such a correction for lateral spreading would not only increase the value of the reams of infiltrometer data that are available but make it possible to adjust field data to meaningful quantitative values.

Several studies that have been conducted within the past 20 years have fully demonstrated that infiltration characteristics are dependent upon fundamental hydraulic properties of soil in relation to water movement. These studies have demonstrated that, by defining such soil properties adequately and describing their effects upon the flow system by means of partial differential equations, solutions can be obtained which show close agreement with laboratory and field observations. Solutions to well-formulated boundary and initial value problems permit various components and features of the flow system to be isolated and studied, thus providing knowledge and insight into extremely complex and otherwise undecipherable cause-effect relationships.

The partial differential equations that describe partially saturated flow in a porous media are nonlinear. Consequently, the majority of available solutions have been obtained for the assumption of one-dimensional flow.

The more general boundary and initial conditions have required investigators to obtain solutions by numerical methods. Solution of the partial differential equations requires a relationship of saturation and permeability to capillary pressure. Considerable research has been devoted to defining relationships between these variables in a partially saturated soil-water-air flow system.

The problem which will be studied under this research outline is the one-dimensional and the three-dimensional axisymmetric partially saturated flow regimes that result from moisture applied at the surface of a soil core and on plots beneath a rainfall simulator. This study will provide needed analytical methods for describing the infiltration components as part of the total effort by the Northwest Watershed Research Center in developing a physically-based, computer-simulated response model of the entire hydrologic cycle of a watershed.

If the hydraulic properties of soils are defined adequately, resulting effects upon flow systems in soils can be described by solutions to the defining partial differential equations. Various components of a flow system can be isolated and studied by formulating proper boundary- and initial-value problems. Knowledge and insight can be provided into extremely complex, undecipherable relationships.

The theory of porous media flow used in this study is also applied to describe the two-dimensional flow system resulting from melting snow over the upper portion of a watershed slope (Research Outline Ida-Bo-105.5). The equipment and some of the procedures developed for this study will be utilized in determining the hydraulic properties of soils, particularly the moisture characteristic, as a cooperative study with Oregon State University.

<u>Design of Experiment and Procedure to be Followed:</u>

1. <u>Variables</u>--

   a. Hydraulic conductivity of the various soil layers.
   b. Moisture content of the various soil layers.
   c. Soil moisture tension.
   d. Soil profile and physical characteristics.
   e. Rate of water application.
   f. Free water detention of soil-cover complexes.

2. <u>Data to be Obtained</u>--Data will be obtained for the variables listed above. Hydraulic conductivities, moisture contents, and moisture tensions will be obtained in 3 different ways: (1) under carefully controlled laboratory conditions at Oregon State University, (2) under field-simulated conditions at the Reynolds Creek Rainfall Simulator Laboratory, and (3) <u>in situ</u>. The soil profile and physical characteristics such as porosity and bulk density will be determined by

digging open pits and taking gravimetric samples. The rate of moisture application can be controlled and will be varied systematically to determine its effect upon the resulting flow system.

3. Procedure--Mathematical models of steady and transient one-dimensional flow and three-dimensional axisymmetric flow through partially saturated soils are currently being perfected by Dr. R. W. Jeppson at the Utah State University Water Research Laboratory under a cooperative study. These models will satisfy objective No. 1.

Objective No. 2 is being pursued concurrently with objective No. 1. Previously published soils data, not necessarily from the Reynolds Creek Experimental Watershed, will be used initially to investigate the importance of lateral spreading. As more data are obtained from the Reynolds Creek Watershed soils, they will be used to verify the model and also to satisfy objective No. 3.

The laboratory phase of objective No. 3 will be acooperative effort with Oregon State University under a cooperative study. The laboratory investigations will be conducted at Oregon State University and at the Reynolds Creek Rainfall Simulator Facility. Disturbed and undisturbed soil cores from Reynolds Creek Experimental Watershed will be tested in the laboratories. Results will be compared to those obtained from the mathematical models.

Following completion of the laboratory phase of objective No. 3, field testing phase will be initiated. The rainfall simulator with its gamma probe infiltrometer is portable, so it can be transported to various sites on the Reynolds Creek Experimental Watershed. Data similar to that obtained in the rainfall simulator laboratory will be obtained in situ for several different soil-vegetation complexes.

Since soil moisture tension and conductivity data are difficult to obtain, especially in situ, parameter optimization will be utilized to achieve objective No. 4. A suitable analytic or parametric model for the saturation-capillary pressure relationship is to be obtained in a cooperative study with Oregon State University. Results from the laboratory phase of objective No. 3 will be utilized in a parameter optimization technique, using the mathematical model and a modified Burdine Theory as an alternative to using soil moisture tension and saturation conductivity data. If parameter optimization can successfully be used to replace soil moisture tension and saturated conductivity data, then ensuing studies would not have to include such data.

In order to separate out the potential quantity of water retainable by soil-vegetation complexes and the potential quantity that is independent of infiltration, the rainfall simulator will be used to apply a given quantity of water at the same initial soil moisture conditions for a range of time intervals. Data obtained in this manner will be used to extrapolate to an instantaneous retention of water for the various soil-vegetation complexes.

Experimental Data and Observations:

1. Instrumentation--The conceptual analytical infiltration model was conceived and formulated on the premise of available or developable mathematical models, access to large electronic computers, and of acquirable new instrumentation for field measurement of the necessary hydraulic and physical soil properties.

A rainfall simulator-gamma probe-infiltrometer has been built as a cooperative effort with the University of Idaho and put into operation during 1970. The 6 by 6-foot unit is composed of 2 by 3-foot double compartment modules supported at a height of 8 feet by a collapsible frame. Capillary needles on 3 by 3-inch centers extend from the water compartment through the air compartment and an orifice in the lower plate from which air flows for controlling drop size. Controls are available for regulating the water and air pressure.

Two sets of modules have been built with different sizes of capillary needles. The larger needles, 0.027 inch (I.D.), will deliver water at a rate of 0.5 to 4.0 inches/hour, and the smaller needles, 0.016 inch (I.D.), will deliver water at a rate of 0.15 to 2.0 inches/hour, with drop sizes controlled by varying the air pressure.

The two-probe (gamma) density gage is operated by a pulley and drive mechanism from the top of the rainfall simulator. Access tubes extend through the modules and connect to access tubes in the soil. The control system makes it possible to obtain density changes (water content changes) simultaneously with the movement of water into the soil profile. Soil water content, therefore, can be monitored at tensiometer locations for development of capillary pressure-saturation relationships.

The Troxler Model SC-10, two-probe (gamma) density gauge, first used, was found to be too temperature sensitive to meet field measurement requirement. That gauge has been replaced by a Troxler Model 2376, two-probe density gauge, which utilizes a tracking differential, Pulse Height Discriminator (PHD) system. The PHD operates with a scintillation probe consisting of a photomultiplier tube which is optically and mechanically coupled to a Thallium activated Sodium Iodide crystal doped with Americium 241. The function of the PHD is twofold:

(a.) It selects pulses of a predetermined height and within a predetermined window to allow density measurements with small composition error.

(b) It compensates for changes in the gain of the photomultiplier tube and the characteristics of the Sodium Iodide crystal due to temperature.

Two tests were made with the new PHD system to determine its temperature stability. First, a series of density readings were made in the laboratory at 3 temperature levels using the magnesium standard. Second, an actual infiltration test was run in the laboratory with the probe remaining stationary at 4 inches below the soil surface.

Data obtained in the first test are tabulated in Table 1. The means and standard deviations for the 3 samples and for the combined data are tabulated at the bottom of the table.

The second test of the PHD system was made in connection with a laboratory infiltration test on a large disturbed soil core to observe capillary pressure and saturation changes with passage of the wetting front. The counts as a function of time for the range of saturation, 55 to 85 percent, are shown in Figure 3.[1] The corresponding change in saturation and capillary pressure is plotted in Figure 7. The gamma probe was stationary during this test at 4 inches below the soil surface.

Capillary pressure or soil water tension measurements, such as those in Figures 4 and 7, were obtained with ceramic cups and pressure transducers. This equipment will be used for tension measurements up to 0.8 bar, and psychrometers will be used for tension in excess of 1-2 bars. Scanivalves are available to allow multiple readings of tensiometers, but experience has demonstrated that a sufficient time must be allowed for equilibrium in the system before reliable readings are obtained.

A small laboratory facility has been built at the Reynolds Creek Experimental Watershed Headquarters to accommodate large soil cores with a 5-foot deep pit the size of the rainfall simulator or 6 by 6 feet. The rainfall simulator-gamma probe-infiltrometer is portable and will be used in both the laboratory and field studies.

1/ Figures follow page 9-19.

TABLE 1.--One-minute counts by two-probe density gauge (PHD system) at different temperatures for magnesium standard with means and standard deviations.

Counts		
Temperature		
37° ± 2°F	73° ± 5°F	80° ± 5°F
10179	10227	10189
10064	10203	10144
10139	10224	10167
10154	10239	10264
10194	10367	10069
10169	10247	10276
10096	10164	10266
10254		
10279	10202	10402
10213	10348	10122
10034	10071	10092
10105	10346	10267
10131	10274	10164
10123	10165	10139
10230	10133	10288
10283	10144	10227
10262	10371	10122
10345	10193	10202
10173	10230	10115
10264	10164	10417
	10243	10301
$\bar{X}_1$ = 10193	$\bar{X}_2$ = 10228	$\bar{X}_3$ = 10212
σ_1 = 76	σ_2 = 80	σ_3 = 95

Combined Data: $\bar{X}$ = 10211

σ = 85

2. Laboratory Data--To date, moisture content data, capillary pressure (moisture tension) data, and hydraulic conductivity data have been obtained by two different methods using disturbed soil samples extracted from a pit on the Summit Watershed W-12, a subbasin of the Reynolds Creek Experimental Watershed. These data have been obtained (a) by using a 2-inch diameter core under carefully controlled laboratory conditions at Oregon State University and (b) by using 14-inch and 60-inch diameter cores at the Reynolds Creek Rainfall Simulator Laboratory.

The capillary pressure-saturation data obtained for the 2-inch cores are illustrated in Figure 4 and are listed in Table 2. The data in Table 2 have been smoothed to provide for a continuous polynomial curve-fitting between each adjacent three data values. The intrinsic permeability-capillary pressure data obtained for the 2-inch cores are illustrated in Figure 5.

The 14-inch core was packed with the disturbed Summit soil sample to see if the results that were obtained from the 2-inch core under carefully controlled laboratory conditions could be duplicated under a field-simulated situation with the rainfall simulator and its associated gamma probe. The 14-inch diameter was necessary to allow for the span of one foot between the gamma probe and its detector. Water was applied by the rainfall simulator over the entire 14 inches of surface diameter to provide a vertical, one-dimensional moisture movement.

Following the test with the 14-inch core, a 60-inch diameter core was packed with the disturbed Summit soil sample to obtain data to verify Jeppson's mathematical model of transient, three-dimensional axisymmetric flow through partially saturated soils. Since water was only applied to an area having a 14-inch diameter, data were obtained to quantify the lateral "spreading effect" of moisture movement from a circular application area.

Three tests using the 60-inch sample were run. During the first test tensiometers were located near the center of the sample and the water application area at depths of 3 and 12 inches below the soil surface. Additional tensiometers were located at a depth of 3 inches and at a radius of 9 inches (2 inches beyond the area receiving water), 12 inches, and 15 inches from the center of the sample. The effect of lateral spreading at the 3-inch depth is illustrated in the saturation-time curves in Figure 6.

A second test was run with the 60-inch sample four weeks after the first test. The second test was deemed necessary to perfect the techniques and instrumentation used to collect the data. In the previous test quite a lot of scatter was noticed in the capillary pressure data. This scatter was

TABLE 2.--Smoothed capillary pressure-saturation data for Reynolds Creek Summit Soil.1/

Capillary Pressure Head (Feet)	Degree of Saturation (Percent)
0.000	.939
0.066	.882
0.131	.852
0.194	.832
0.259	.817
0.325	.796
0.390	.788
0.456	.775
0.522	.762
0.587	.750
0.650	.732
0.748	.711
0.813	.692
0.978	.649
1.138	.608
1.302	.572
1.434	.540
1.594	.508
1.693	.492
1.759	.485
1.824	.475
1.890	.466
1.988	.455
2.152	.439
2.280	.418
2.543	.391
2.887	.374
3.258	.349
4.206	.310
6.114	.268
9.288	.241

1/ Taken from Jeppson, R. W. 1970. Solution to transient vertical moisture movement based upon saturation-capillary pressure data and a modified Burdine Theory. Progress Report PRWG-59c-5. Utah Water Research Laboratory, Utah State University, Logan. Raw data were smoothed so that a second degree polynomial could be passed through each three consecutive values without erratic behavior.

attributed to excessive switching of the Scanivalve used to connect the hydraulic lines leading from the tensiometers to a single pressure transducer. To eliminate the excessive switching of the Scanivalve required in the first test, only two tensiometers were used during the second test. These tensiometers were located at a 3-inch radius from the center and at depths from the surface of 3 inches and 9 inches, respectively. Data scatter was essentially eliminated in this test.

A third test was deemed necessary, since saturation-time curves obtained for the second test with the gamma probe did not correspond closely to the saturation-time curves derived from the capillary pressure data (for the second test) and the capillary pressure-saturation curve (Figure 4) developed from the 2-inch core. The discrepancies noted in the results of the second test were attributed to the possibility that the gamma probe and tensiometers were not at corresponding elevations in the sample when readings were taken. The third test was run 6 weeks after the second test. Two tensiometers were located near the center of the sample and at a depth of 4 inches below the soil surface. Extreme care was used in placing the gamma probe exactly at the same elevation as the two tensiometers. During the test the gamma probe was not moved from that position. A better agreement was achieved between saturation-time curves obtained with the gamma probe and derived from the capillary pressure data. The capillary pressure-time curve obtained with the tensiometers and the saturation time curve obtained with the gamma probe are illustrated in Figure 7.

3. Mathematical Model Data--The solution to the partial differential equations that describe transient, one-dimensional vertical flow, and transient, three-dimensional axisymmetric flow through partially saturated soils depends upon obtaining values for (a) the change in saturation with capillary pressure, (b) the relative hydraulic conductivity (ratio of partially saturated hydraulic conductivity to saturated hydraulic conductivity), and (c) the change of relative hydraulic conductivity with capillary pressure. Of these needed quantities, it is more practical to obtain capillary pressure-saturation data in the laboratory or field with tensiometers and either neutron meters or gamma probes. Hydraulic conductivity-capillary pressure data are much more difficult to obtain. Consequently, it is desirable to obtain values for relative hydraulic conductivity and the change of relative conductivity with capillary pressure from saturation-pressure data, or from some functional relationship involving pressure. Such functional relationships have been proposed in the literature; i.e., the Brooks-Corey Equation. This relationship did not give close agreement to the data obtained from the soil taken from the Summit on the Reynolds Creek Experimental Watershed. However, reasonable results are obtained by using a modification of the Burdine Theory with capillary pressure-saturation data.

Illustrated in Figure 8 is a comparison of the observed saturation-pressure data (for the Summit soil) with that given by the Brooks-Corey Equation. A comparison of observed hydraulic conductivity-pressure data with that obtained by the Brooks-Corey Equation and with that obtained from saturation-pressure data through the modified Burdine Theory is illustrated in Figure 9. Since better agreement to laboratory data is obtained by using the modified Burdine Theory, it has been incorporated in the mathematical model, rather than in the Brooks-Corey Equation.

In order to evaluate quantitative effects on the flow pattern from water applied at the surface of a circular infiltrometer, comparisons are needed between results obtained from one-dimensional vertical flow and three-dimensional axisymmetric flow models. The formulation and solution method for both models are consistent and compatible. For the data obtained from the Summit soil, results obtained from the two models indicate that boundary effects on circular infiltrometers significantly alter the flow pattern, even reducing the saturation at the surface centerline appreciably over that which would exist for the same application rate over an infinite area.

Figures 10 and 11 illustrate the capability of the transient, three-dimensional axisymmetric flow model. Isosaturation lines are plotted at two different time steps, $\tau = K_o t$ (K_o is saturated hydraulic conductivity and t is time). For the problem illustrated in Figures 10 and 11, the initial capillary pressure head in the soil, h_o, is -5.0 feet of water, and the water is applied over a circle of one-foot radius at a rate less than the intake capacity of the soil. Consequently, nowhere does the soil become completely saturated.

In addition to Figures 10 and 11, Figure 12 illustrates in another manner the effect of lateral spreading from a circular infiltrometer. The saturation-time curves are for the 3-inch depth and for radii which are consistent with the curves illustrated in Figure 6 for the laboratory data.

Comments, Interpretations, and Future Plans:

1. Instrumentation--The essential instrumentation components have been designed or procured. The major unit, the rainfall simulator-gamma probe-infiltrometer is in complete operational condition. This unit, with a combination of needle sizes, and air and water pressures, is capable of duplicating the median drop sizes of natural rainfall up to intensities of over 4 inches/hour. In Figure 1, the drop diameter of simulated rainfall at intensities of 0.5 and 4.0 inches/hour are compared with those of natural rainfall. The control of drop sizes and intensities also make it possible to produce a desired rainfall energy even though terminal velocities are not reached.

Each of the data sets obtained on density by the PHD system at three different temperatures, Table 1, were found to be normally distributed when plotted on arithmetic probability paper. In addition, an analysis of variance was made to test significance between the average of the three data sets by use of the F-test. The ratio of the variance between samples, 6315, to the variance within samples, 7432, is 1.18. For 2 degrees of freedom for the smaller variance and 57 degrees for the larger variance, the value of F for a probability of 95 percent is 19.47. Since the variance ratio, 1.18, is not significantly larger than 1, the difference between the means of the samples is not significant.

The differences in variance between the 3 samples is, likewise, not significant since the variance ratio is small; i.e., $F = \sigma_3^2 / \sigma_2^2 = 1.56$ (Table 1). Using 19 degrees of freedom for each sample, the F value for a probability of 95 percent is 2.14. It is concluded, therefore, that the observed counts (density) obtained by the density gage, utilizing the PHD system is not significantly affected over the temperature range of 37° to 80° F.

As a result of the analysis of variance, the 3 samples of data (Table 1) were combined for determining the random errors of measurements for 1-minute counts. An arithmetic probability plotting of the combined data is shown in Figure 2. The standard error, S. E. (standard deviation σ), is 85 with SE = 0.83 percent. The probable error, P. E. (50 percent error), obtained from the S. E. is 54 with P. E. = 0.52 percent. Using the actual values, the average deviation, A. D. is 70.

For the 30-percent increase in saturation, the counts decreased from 8675 to 7120 (mean of 7738), with an average deviation, A. D., of 41 from the curve of equal deviations (Figure 3). A change of 1-percent saturation represents 51.8 counts. The A. D. of the counts is 0.5 percent, corresponding to the P. E. of 0.52 percent for the first test. The probable error in measured saturation for the saturation range from 55 to 85 percent is 0.63 percent or (51.8 × 0.005)/41 = 0.0063.

Data obtained on saturation by the rainfall simulator-gamma probe-infiltrometer and by the tensiometer-transducer system indicates that procurement of such data can be reliably obtained in the field. Saturation and tension data will be obtained in the laboratory from large, undisturbed soil cores (5 feet in diameter and 5 feet deep) before initiating field data procurement this coming summer.

2. Laboratory Data--Results obtained in the initial laboratory tests at Oregon State University (Figures 4 and 5 and Table 2) on the 2-inch diameter, disturbed, Summit soil samples demonstrate (Figures 8 and 9) that the Brooks-Corey Equations did not describe very well the soil's partially saturated behavior. This fact led to the modification of the Burdine Theory for application to the imbibition phase.

The test on the 14-inch diameter disturbed soil core was conducted for three purposes. The first objective, as mentioned earlier, was to try to duplicate the results that were obtained with the 2-inch diameter disturbed soil core, since a different laboratory and different equipment were to be utilized. The second objective was to provide data to test Jeppson's transient, one-dimensional vertical moisture-movement model. The third objective was to develop testing procedures and to determine whether or not modifications to the equipment were necessary to obtain adequate laboratory and field data. The latter objective was necessary since the Reynolds Creek Rainfall Simulator Laboratory was a new facility, and some of the electronic instrumentation was new.

The tests that were conducted on the 60-inch diameter disturbed soil sample were necessary to provide data to test the transient, three-dimensional axisymmetric flow model and to further perfect testing procedures. Two major problems associated with the data obtained from the first two tests appear to be solved. Excessive scattering of the capillary pressure data was apparently caused by excessive switching of the Scanivalve. Poor agreement between saturation-time curves for the gamma probe and tensiometers was apparently caused by a discrepancy between the elevations of the probe and the tensiometer.

In the interest of space, only the more pertinent of the laboratory data has been presented and discussed here. Data not presented here include: (a) data obtained from the 14-inch, one-dimensional test, (b) vertical spreading data from the first axisymmetric test, and (c) data obtained from the second axisymmetric test.

3. Mathematical Model Data--As mentioned earlier, the Brooks-Corey Equations did not describe very well the behavior of the saturation-pressure and hydraulic conductivity-pressure trends observed for the Summit soil. A modification to the Burdine Theory provides a functional relationship for relative hydraulic conductivity in terms of pressure-saturation data that gives reasonably close agreement to the laboratory data. The results from the Burdine Theory are given by the following equation:

$$K_r = S_e^2 \frac{\int_{S_r}^{S} \frac{dS}{p^2}}{\int_{S_r}^{1} \frac{dS}{p^2}} \qquad (1)$$

where K_r is relative conductivity, p is capillary pressure, and S_e is the effective saturation defined by $S_e = (S-S_r)/(1-S_r)$, in which S_r is the residual saturation. The latter quantity is physically the saturation at which moisture movement stops, but it is generally taken to be the value that gives as good a fit as possible to a functional relationship between S_e and p.

To date, the Burdine integrals, Equation (1), have been applied to the case of desaturation (drainage). For problems dealing with imbibition (wetting), Equation (1) must be modified, since capillary pressure p becomes zero for values of S slightly less than unity. This would result in a division by zero. Two modifications have been introduced to the Burdine integrals. First, a constant pressure p_o has been added to the capillary pressure p; and second, the upper limit of the integral in the denominator has been changed to S_o, a value that has a magnitude slightly less than unity and at which the capillary pressure p becomes zero. With these modifications the Burdine integrals of Equation (1) become

$$K_r = S_e^2 \frac{\int_{S_r}^{S} \frac{dS}{(p+p_o)^2}}{\int_{S_r}^{S_o} \frac{dS}{(p+p_o)^2}} \qquad (2)$$

The introduction of S_o and p_o results in additional parameters that are needed to describe the hydraulic properties of a soil. A value of S_o can be obtained from saturation-pressure data when p = o. Further studies are needed to relate the value of p_o to the physical properties or to some measurable hydraulic characteristic of the soil. In the absence of such studies, the value of p_o must be based on judgment that is guided by values obtained by trial for soil for which hydraulic conductivity-capillary pressure data are also available.

From analysis of the limited amount of data from the Summit soil, it appears that values for the relative hydraulic conductivity, K_r, are not highly sensitive to small changes in the value of P_o, particularly in the region in which K_r is not too much less than unity. It is believed that a reasonable estimate of p_o will be adequate for many applications of Equation (2) for two reasons. First, little flux movement exists in regions in which K_r is very small, and second, lack of sensitivity exists in regions where K_r approaches unity. Consequently, hydraulic conductivity-capillary pressure data will not be necessary, but values of saturated hydraulic conductivity will be required.

The saturation-pressure data (Table 2 and Figure 8) for the Summit soil were used in a numerical evaluation of Equation (2). Several values of p_o were used, and the results were compared with the conductivity-pressure data for the same soil. Laboratory data indicated that a value of S_o = 0.939 should be used for the Summit soil, but several values were tested in the mathematical model. Results of the evaluation indicated that values for K_r increased with larger values of p_o over the entire range of capillary pressures. Increases in K_r were more pronounced in the regions of large negative values of capillary pressure, p; whereas, decreases in the value of S_o increased K_r more markedly in the portion of the curve where p approaches zero. Relatively good agreement exists between the values of K_r determined by Equation (2) (with S_o = 0.939 and p_o = 1.0 foot) and the experimental data (Figure 9). Therefore, Equation (2) has been implemented in the mathematical models of partially saturated, transient, one-dimensional vertical flow, and three-dimensional axisymmetric flow in porous media.

The mathematical problem of one-dimensional vertical moisture movement through soils has been solved for this study by finite differences using the Crank-Nicholson method. In this method the differences at the advanced time step are weighted equally with those at the current time step. This technique leads to an implicit method that is stable for all incremental time steps, and, as such, requires the solution of a tridiagonal, coefficient matrix to advance each time step.

An interesting result of the one-dimensional study on the Summit soil sample is that the hydraulic gradient near the soil surface is much greater than the unit gradient that exists for saturated flow in a vertical column. The magnitude of the gradients above unity in the partially saturated flow are the result of capillary forces.

A number of one-dimensional solutions was obtained by specifying several application rates and initial values of hydraulic head, h_o, to correspond to specifications used in obtaining solutions to similarly formulated, three-dimensional axisymmetric problems of flow from

circular infiltrometers. The saturation at the surface centerline of the three dimensional axisymmetric problems is greater than anywhere else at the soil surface, as illustrated in Figures 10 and 11. In fact, saturation approaches initial saturation at some distance from the infiltrometer ring, but it also decreases within the ring.

For all problems at all time steps, the magnitude of the saturation for for the three-dimensional axisymmetric case is less than that for the equivalent one-dimensional problem. The decrease in saturation for the three-dimensional case can be attributed to the radial component of velocity removing some water, even at the centerline. The radial component of velocity appears less significant for lower rates of application, particularly if a low rate of application is specified in conjunction with a relatively large value (small in absolute value) of initial hydraulic head h_o.

The influence of the radial component of velocity (or the spreading effect) is different, depending upon the point being considered. The saturation at the surface near the infiltrometer ring will be less than at the centerline. Table 3 gives a comparison of saturation at the soil surface from one-dimensional solutions with those at the surface centerline and at the infiltrometer ring from equivalently specified three-dimensional axisymmetric problems.
Also of interest is the manner in which the saturation increases at a point within the soil profile as a function of the application rate and of the initial condition. The point selected for illustrative purposes is the soil surface for the one-dimensional problem. Values for the ratio of saturation at the surface divided by the initial saturation, also on the surface, have been plotted (not shown here) against the application rate for several time steps. On these figures different values of initial hydraulic head define separate curves. These figures illustrate (a) how the saturation on the surface increases with smaller values (large in absolute value) of initial hydraulic head and (b) how the surface saturation increases with larger rates of application.

Future plans concerning the laboratory work include extracting a 14-inch diameter core from the 60-inch diameter disturbed Summit soil sample that was last tested. The 14-inch core will be tested under one-dimensional vertical moisture movement conditions to obtain hydraulic conductivity-capillary pressure data. These data will be used to test further the modified Burdine Theory that was mentioned earlier. At the time the 14-inch core is extracted from the larger sample, gravimetric samples will be taken to determine the exact bulk densities and porosities at various depths.

TABLE 3.-- Comparison of saturation at the soil surface from one-dimensional solutions with those at the surface centerline and at the infiltrometer ring from equivalently specified three-dimensional axisymmetric problems.[1/]

Initial head h_o	Applic. rate $\lvert q \rvert / K_o$	Time Parameter τ	R_o = One-Dim. sat./axisym. sat. at centerline	R_1 = One-Dim. sat./axisym. sat. at infiltrometer ring (r=1')	Percent diff. $\frac{R_1 - R_o}{R_o} \times 100$
-0.859	0.0954	.99	1.0081	1.0966	9.5
-2.859	0.0636	1.0	1.0275	1.1379	10.6
-2.859	0.0477	1.0	1.0433	1.1567	10.7
-3.859	0.0636	1.0	1.0285	1.1396	10.3
-1.859	0.0636	1.0	1.0256	1.1304	10.2
+0.141	0.0636	1.0	1.0195	1.0792	5.9
+0.141	0.0954	1.0	1.0150	1.0898	7.4
+0.141	0.159	.75	1.0446	1.0900	4.3
-0.859	0.159	.5475	1.0506	1.1118	5.8
-3.859	0.159	.5	1.0293	1.1299	9.8
+0.141	-.2226	.3	1.0756	1.1461	6.6
-1.859	0.159	.585	1.0415	1.1157	7.1
-1.859	0.2226	.470	1.0729	1.2041	12.1

1/ Taken from Jeppson, R. W. 1970. Solution to transient vertical moisture movement based upon saturation-capillary pressure data and a modified Burdine Theory. Progress report PRWG-59C-5. Utah Water Research Laboratory, Utah State University, Logan.

Following the test for conductivity-pressure data on the 14-inch core, tests will be conducted on a series of 32-inch diameter, undistributed soil cores taken from several different locations on the Reynolds Creek Experimental Watershed that contain different soil types. Four of these cores have already been extracted. Plans call for obtaining two more of the large, 32-inch, undisturbed soil cores. Saturation-pressure data will be obtained from each core in the Reynolds Creek Rainfall Simulator Laboratory by using the rainfall simulator-gamma probe-infiltrometer and the tensiometer-transducer system. Since the modified Burdine Theory appears to give adequate values of relative hydraulic conductivity, present plans do not call for obtaining conductivity-pressure data from the undisturbed soil cores. Data on saturated hydraulic conductivity will be required.

After data have been obtained from each undisturbed soil core, the sample will be broken up, gravimetric samples will be taken, and a disturbed sample will be formed. Saturation-pressure data will then be obtained for each disturbed sample. Comparisons between the data from the undisturbed and disturbed samples can be made, in addition to further analyses of the hydraulic properties of the different soil types. An attempt will be made to determine parametric equations that adequately describe the hydraulic properties, especially the saturation-pressure characteristics, of the Reynolds Creek soils.

Following the laboratory studies described above, further use of the mathematical models will be made. Parameter optimization will be incorporated into the models to determine: (1) the parameters in the saturation-pressure relationships that evolve from analyses of the laboratory data, and (2) the saturated hydraulic conductivity. The laboratory data will provide a check on the parameter-optimization results. If parameter optimization is successful, then less field data will be necessary in future studies.

Future plans concerning field work include in situ tests using the rainfall simulator and its associated gamma probe at various locations that include different soil types on the Reynolds Creek Experimental Watershed. The field data will be used to satisfy three objectives. First, a field verification of the transient, three-dimensional axisymmetric, partially saturated flow model is needed. Second, tensiometers will be installed at some of the test sites to provide field data to further verify the use of the modified Burdine Theory and parameter optimization. Third, for different initial soil moisture levels, field tests will be conducted to determine the potential quantity of water retainable by various soil-vegetation complexes, and the potential quantity that is independent of infiltration.

Publications completed and in preparation since last year's report are the following:

Jeppson, R. W. 1970. Transient flow of water from infiltrometers--formulation of mathematical model and preliminary numerical solutions and analyses of results. Progress report PRWG-59c-2. Utah Water Research Laboratory, Utah State University, Logan.

Jeppson, R. W. 1970. Formulation and solution of transient flow of water from an infiltrometer using the Kirchhoff Transformation. Progress report PRWG-59c-3. Utah Water Research Laboratory, Utah State University, Logan.

Jeppson, R. W. 1970. Determination of hydraulic conductivity--capillary pressure relationship from saturation - capillary pressure data from soils. Progress report PRWG-59c-4. Utah Water Research Laboratory, Utah State University, Logan.

Jeppson, R. W. 1970. Solution to transient vertical moisture movement based upon saturation-capillary pressure data and a modified Burdine Theory. Progress report PRWG-59c-5. Utah Water Research Laboratory, Utah State University, Logan.

Wei, C-Y., and Jeppson, R. W. In Press. Finite difference solutions of axisymmetric infiltration through partially saturated porous media. Progress report PRWG-59c-6. Utah Water Research Laboratory, Utah State University, Logan.

Penton, V. E., and Hamon, W. R. In preparation, 1971. A rainfall simulator, gamma probe, infiltrometer. To be submitted to Water Resources Research.

Jeppson, R. W., Schreiber, D. L., and Biggs, E. N. In preparation, 1971. Verification of a mathematical model of transient water flow from infiltrometers. Water Resources Research.

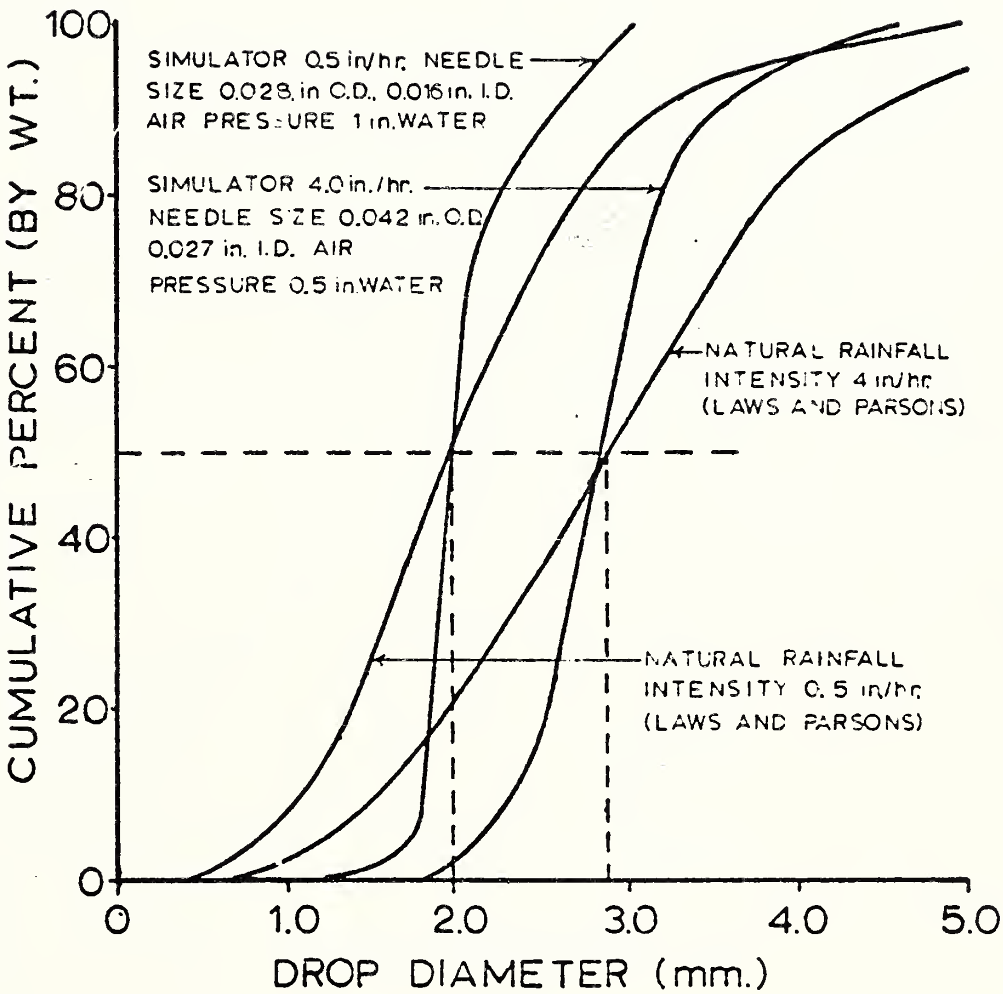

Figure 1. Cumulative percent, by weight, of simulated and natural rainfall in relation to drop diameter.

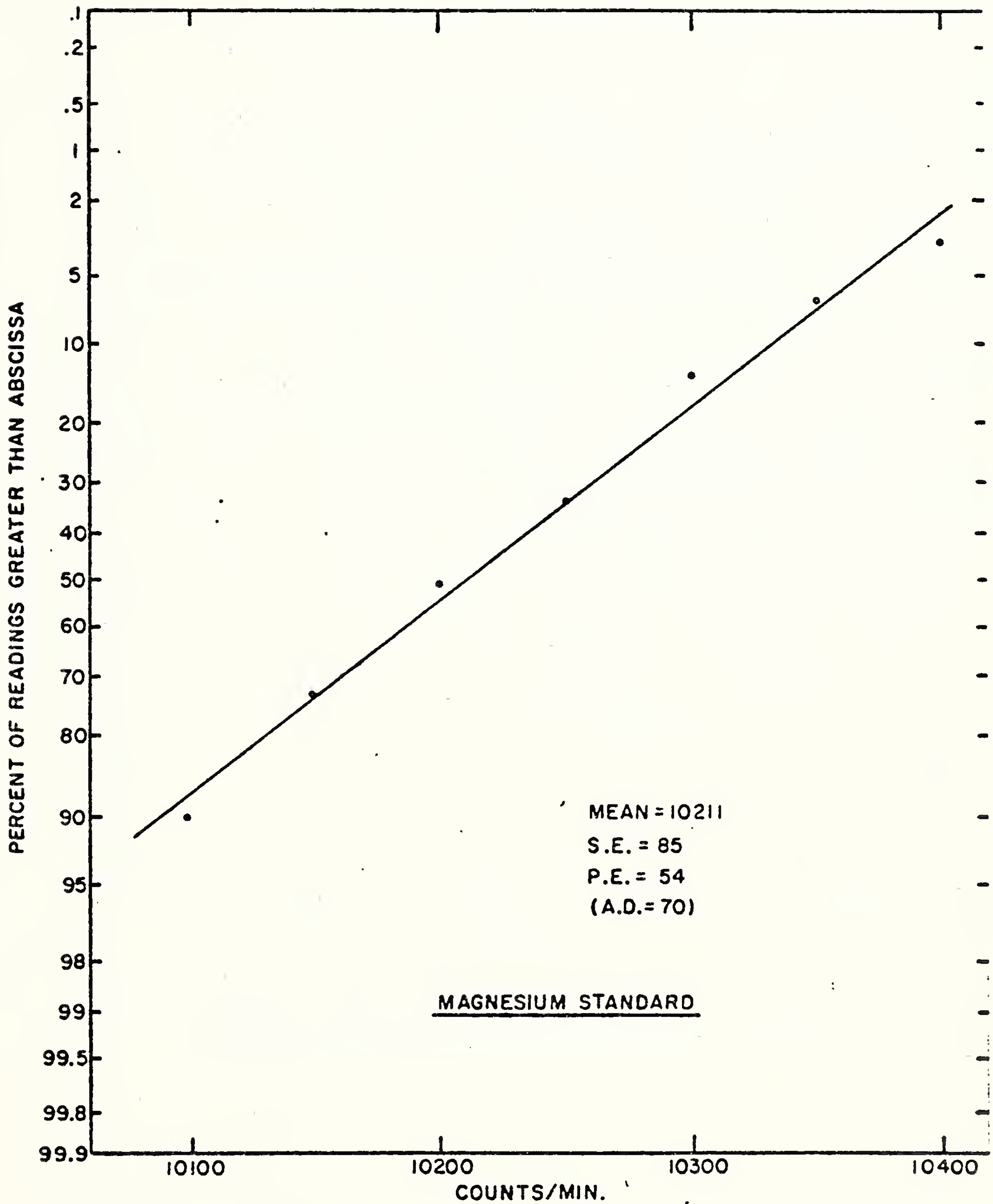

Figure 2. Probability of one-minute gamma probe counts obtained with magnesium standard (Twenty readings at 37°F, 73°F, and 80°F.).

9-22

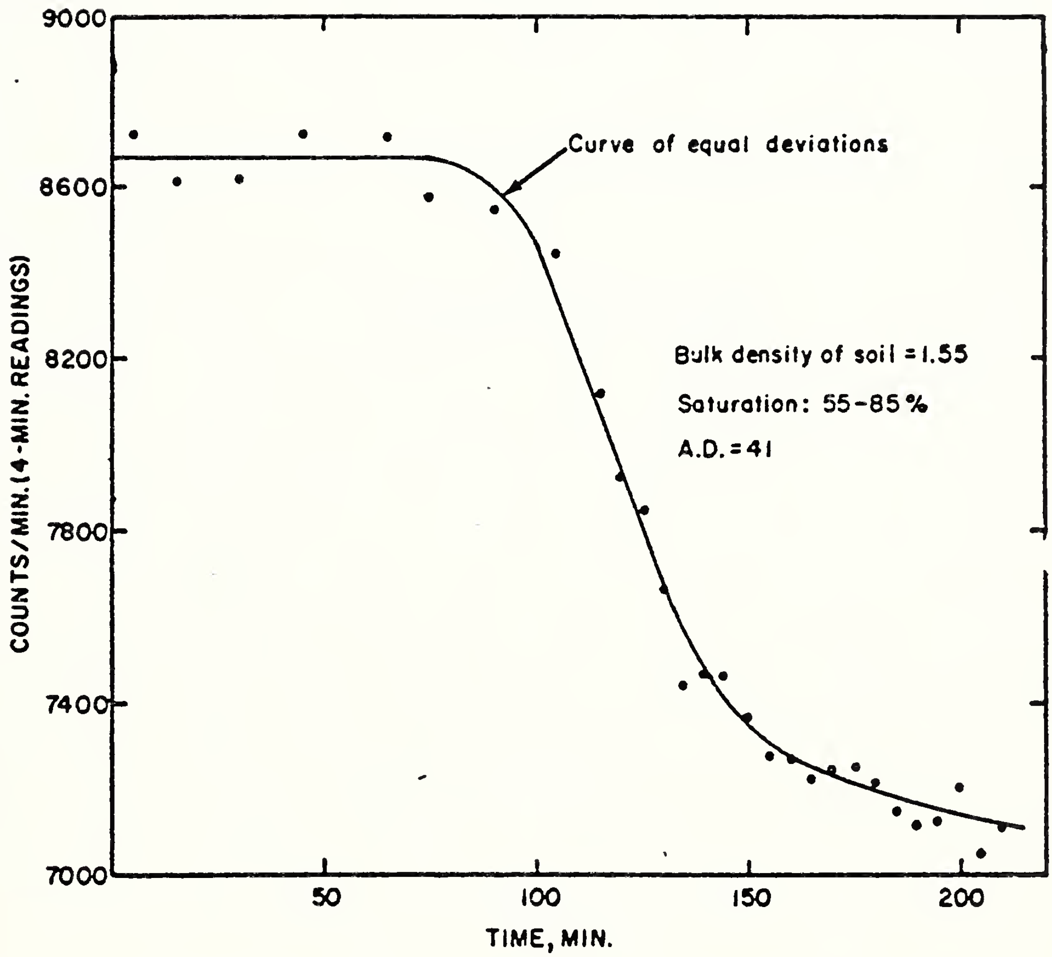

Figure 3. Average gamma probe counts per minute (four-minute readings) during passage of wetting front at four inches below soil surface.

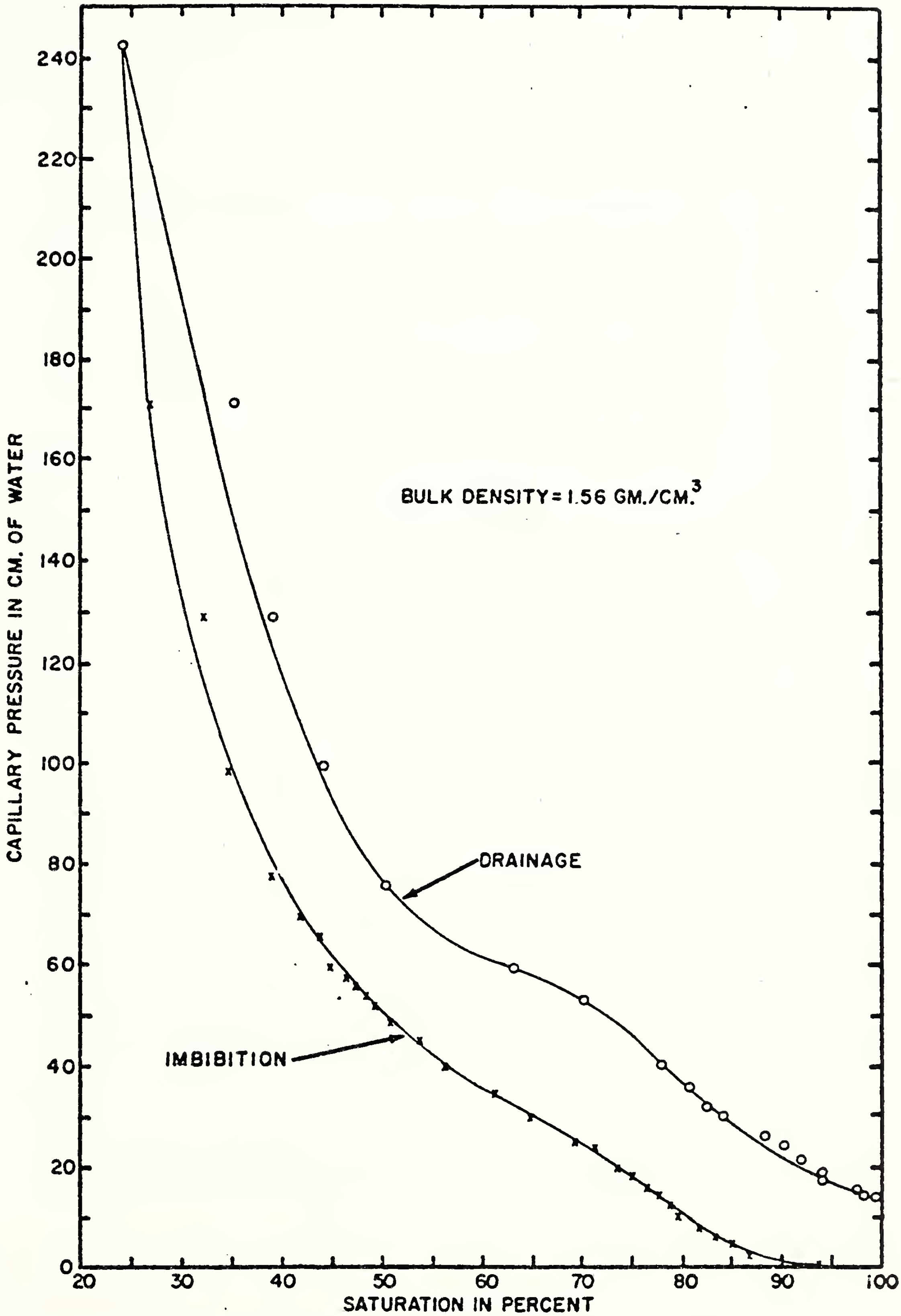

Figure 4. Laboratory saturation-capillary pressure curves for Summit soil.

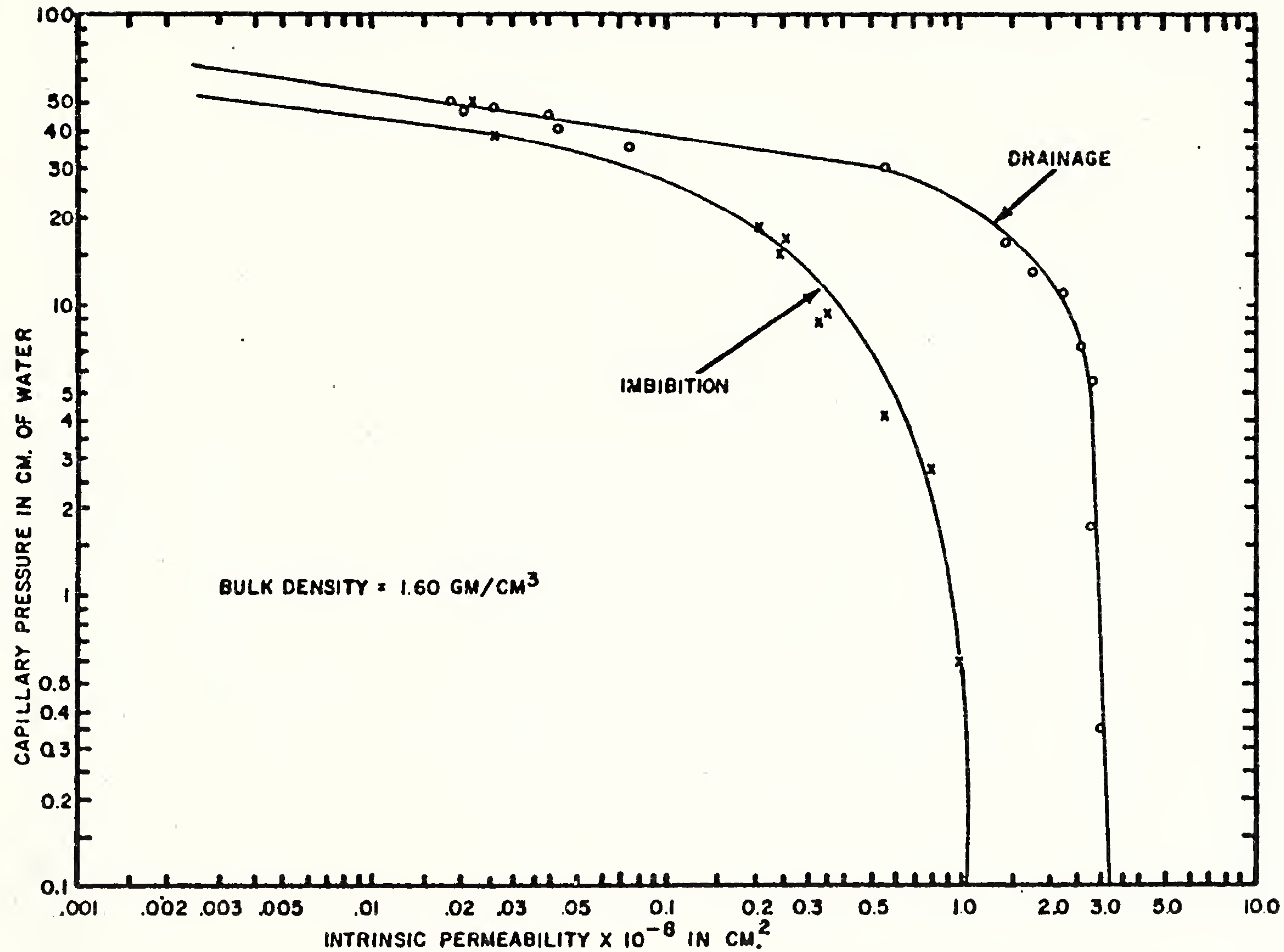

Figure 5. Laboratory intrinsic permeability-capillary pressure curves for Summit soil.

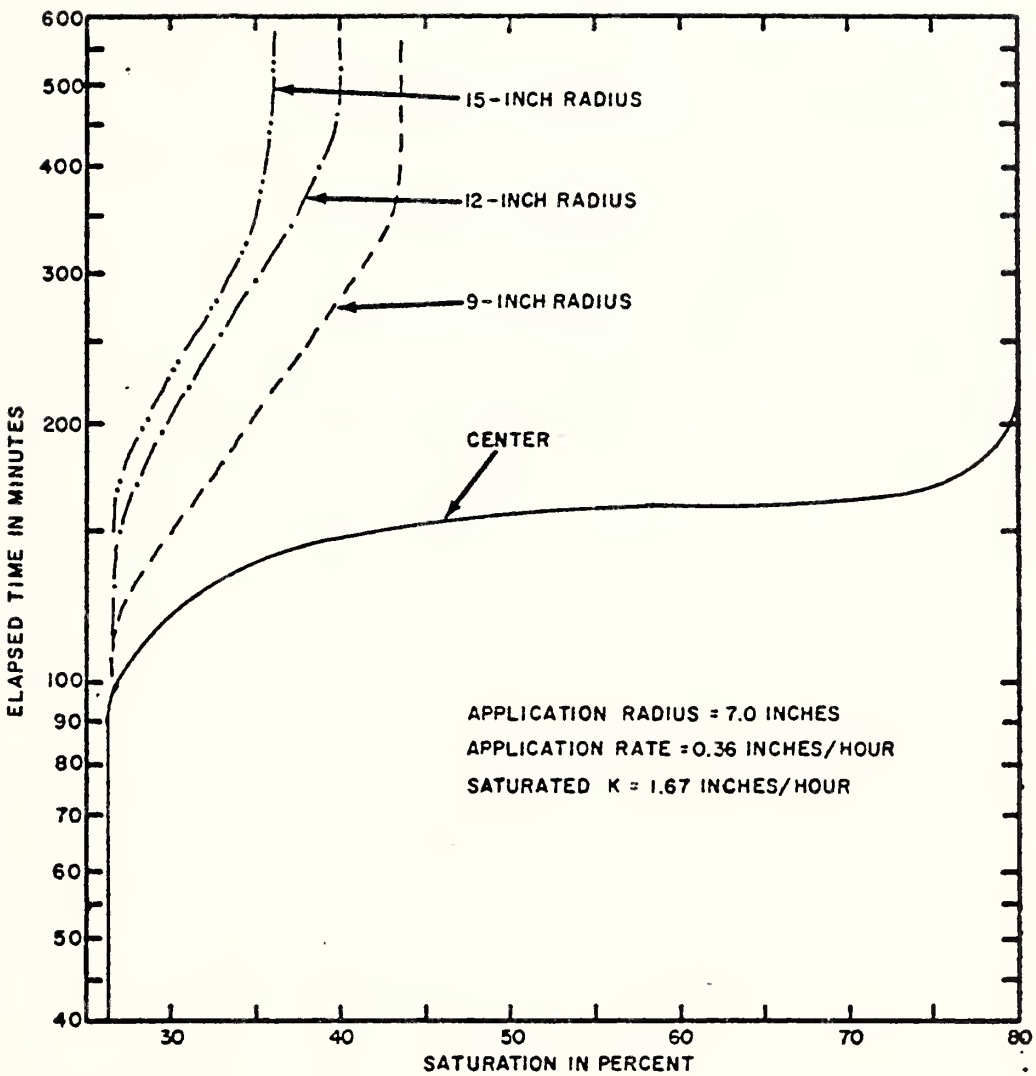

Figure 6. Observed effect of lateral spreading from a circular infiltrometer at a depth of 3 inches in a disturbed Summit soil sample.

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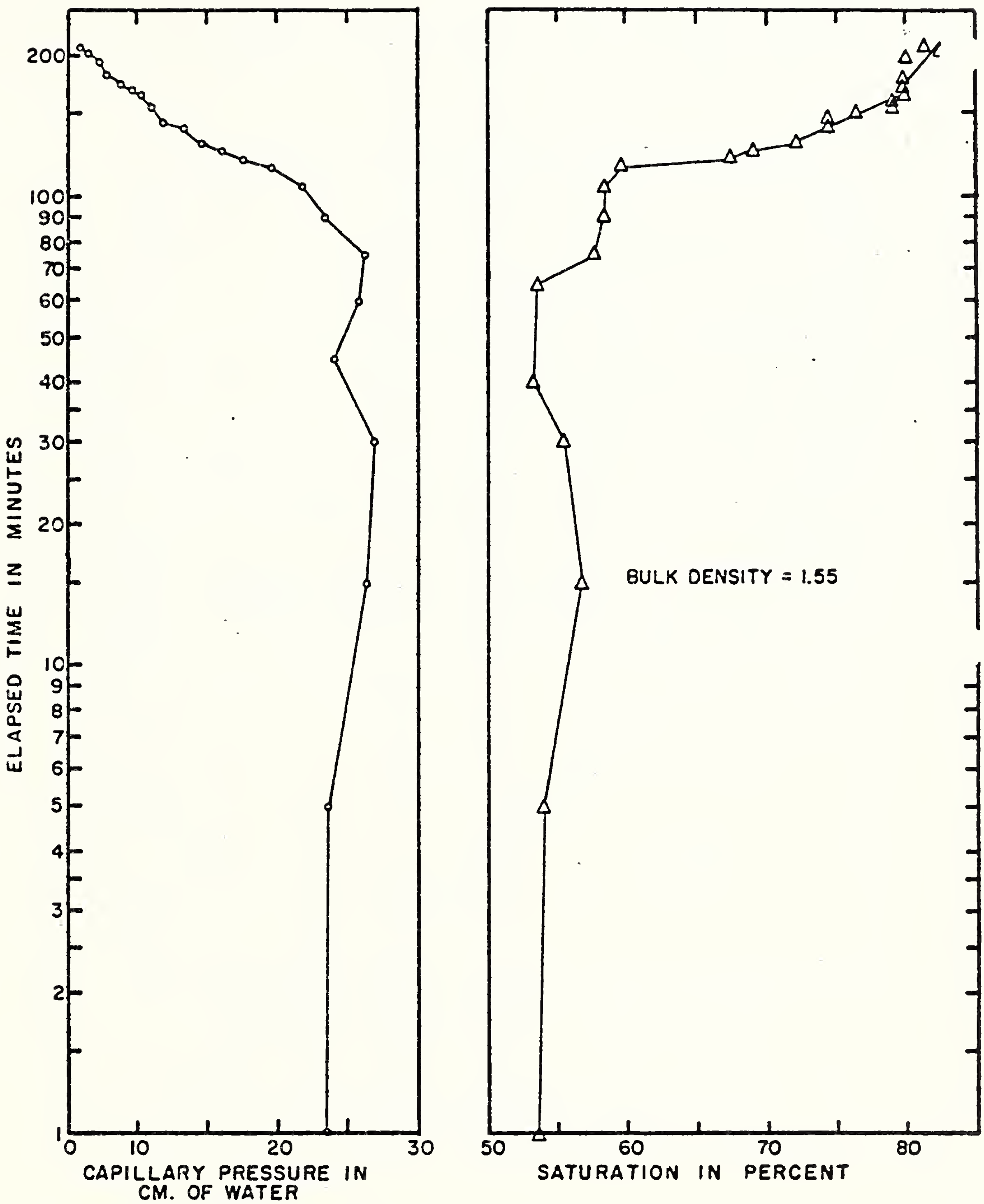

Figure 7. Observed time variations of capillary pressure and saturation at a depth of 4 inches in a disturbed Summit soil sample.

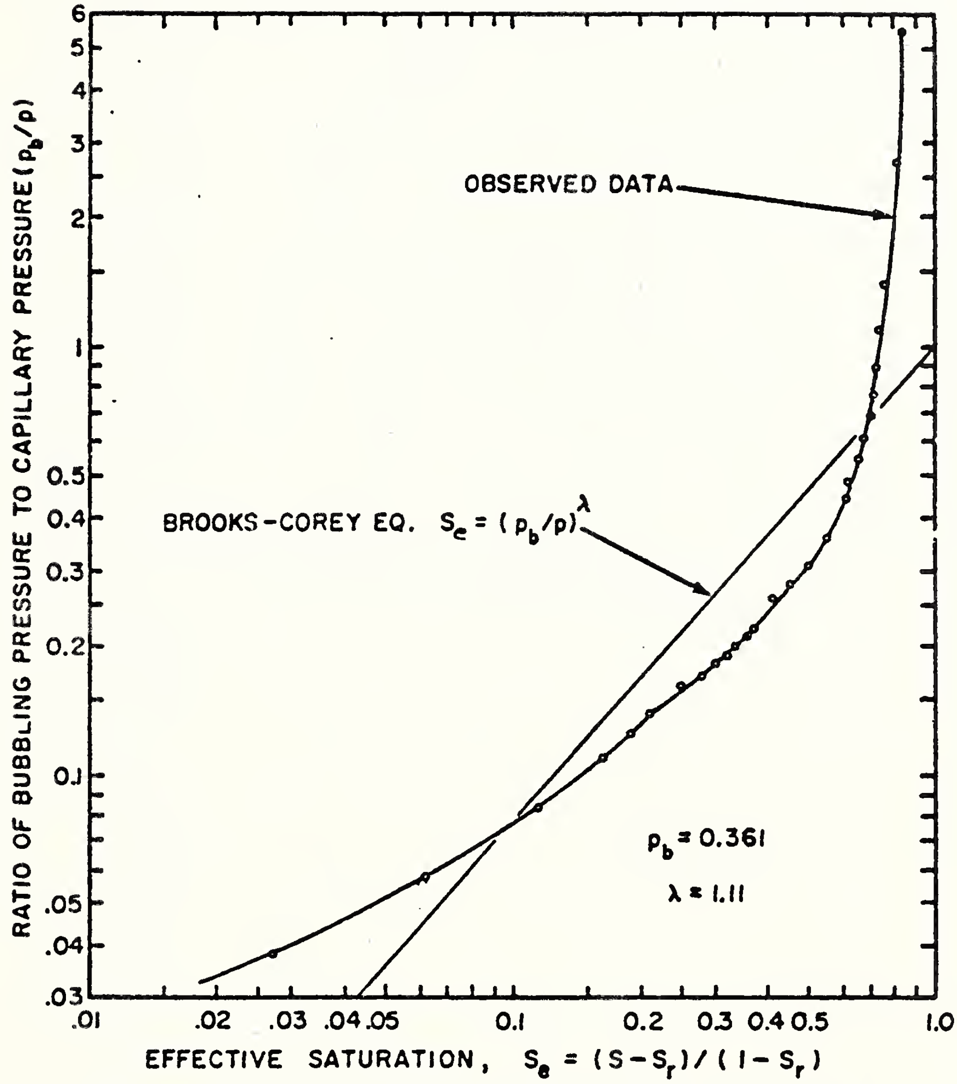

Figure 8. Comparison of observed saturation-pressure data for Summit soil with that predicted by the Brooks-Corey equation.

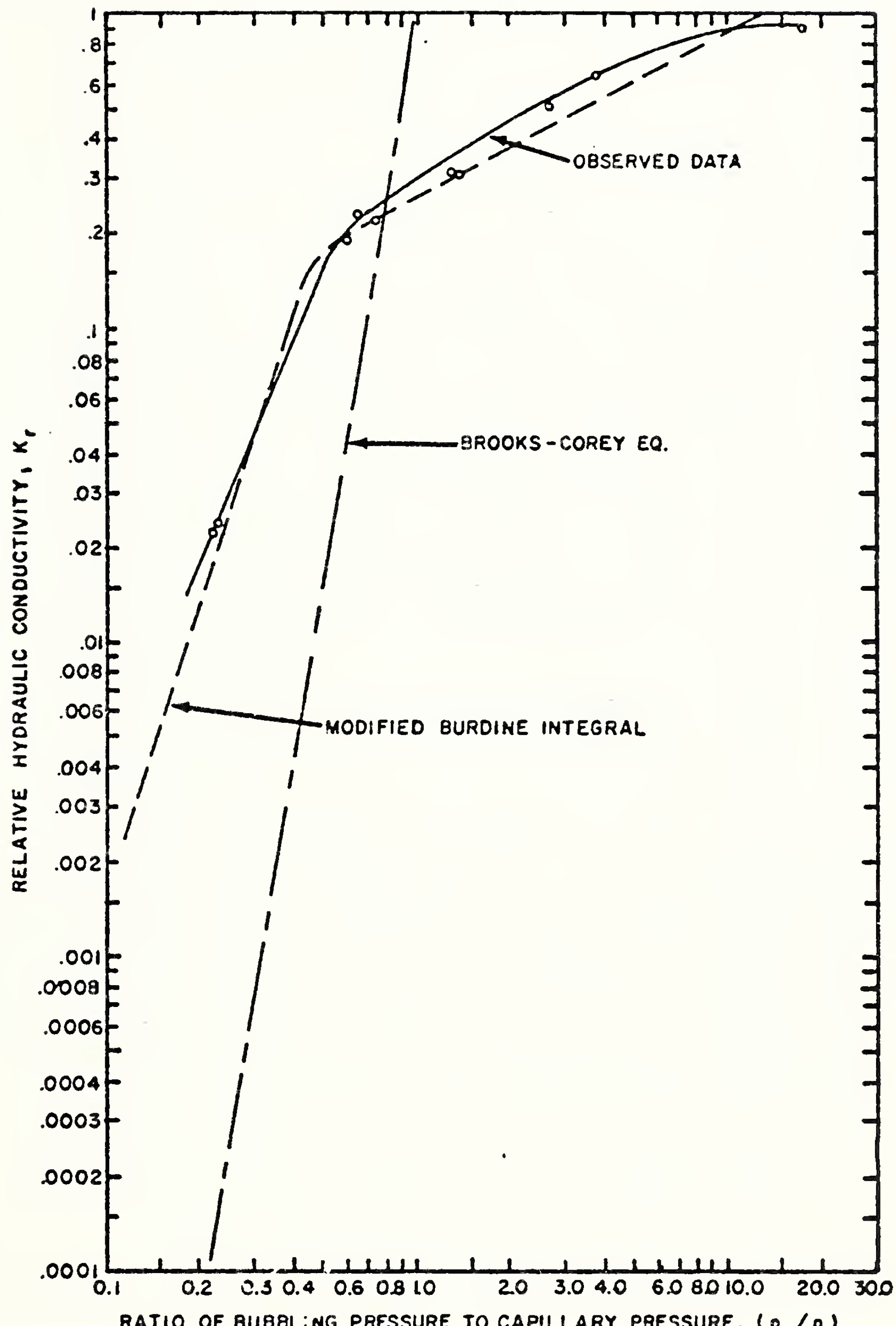

Figure 9. Comparison of observed hydraulic conductivity-capillary pressure data with that obtained by the Brooks-Corey equation and that obtained from saturation-capillary pressure data through a modified Burdine integral.

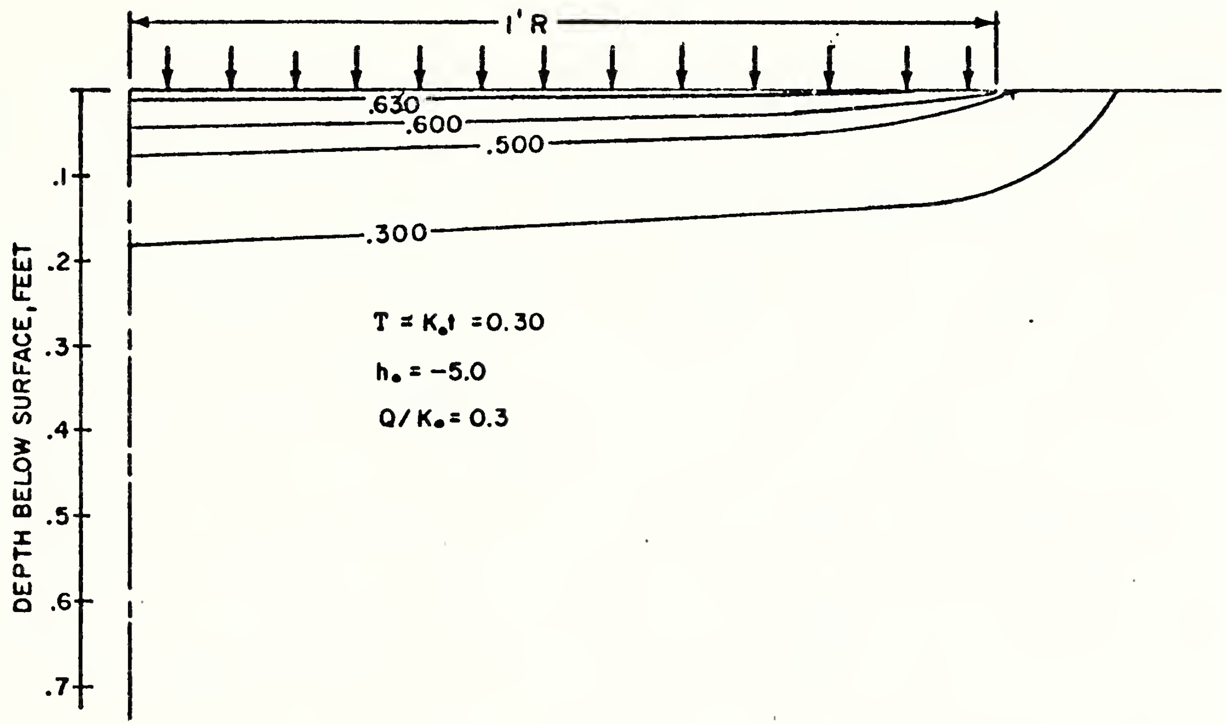

Figure 10. Predicted iso-saturation lines at time step τ=0.30 for flow from a circular infiltrometer.

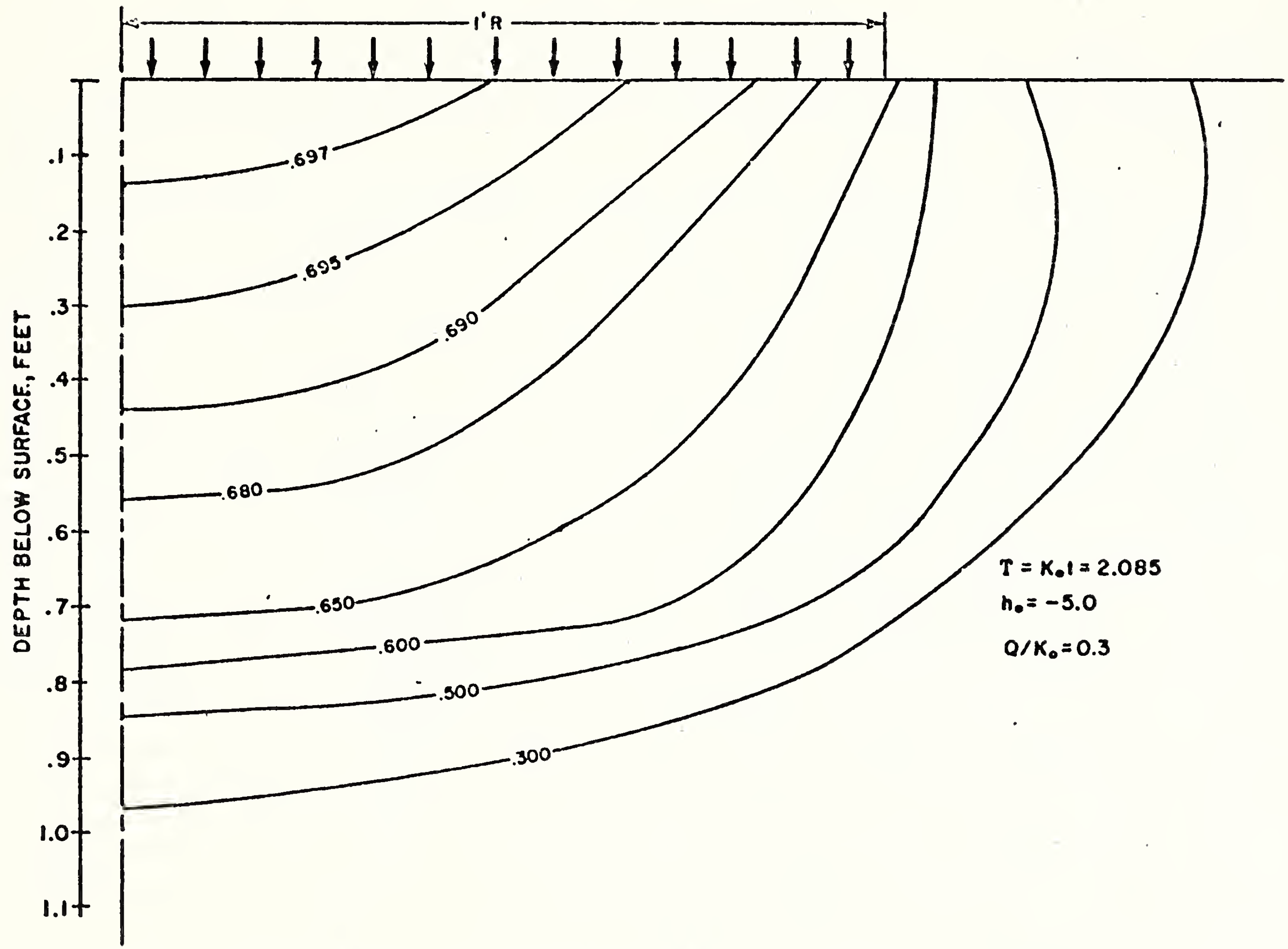

Figure 11. Predicted iso-saturation lines at t' step τ= 2.085 for flow from a circular infiltrc er.

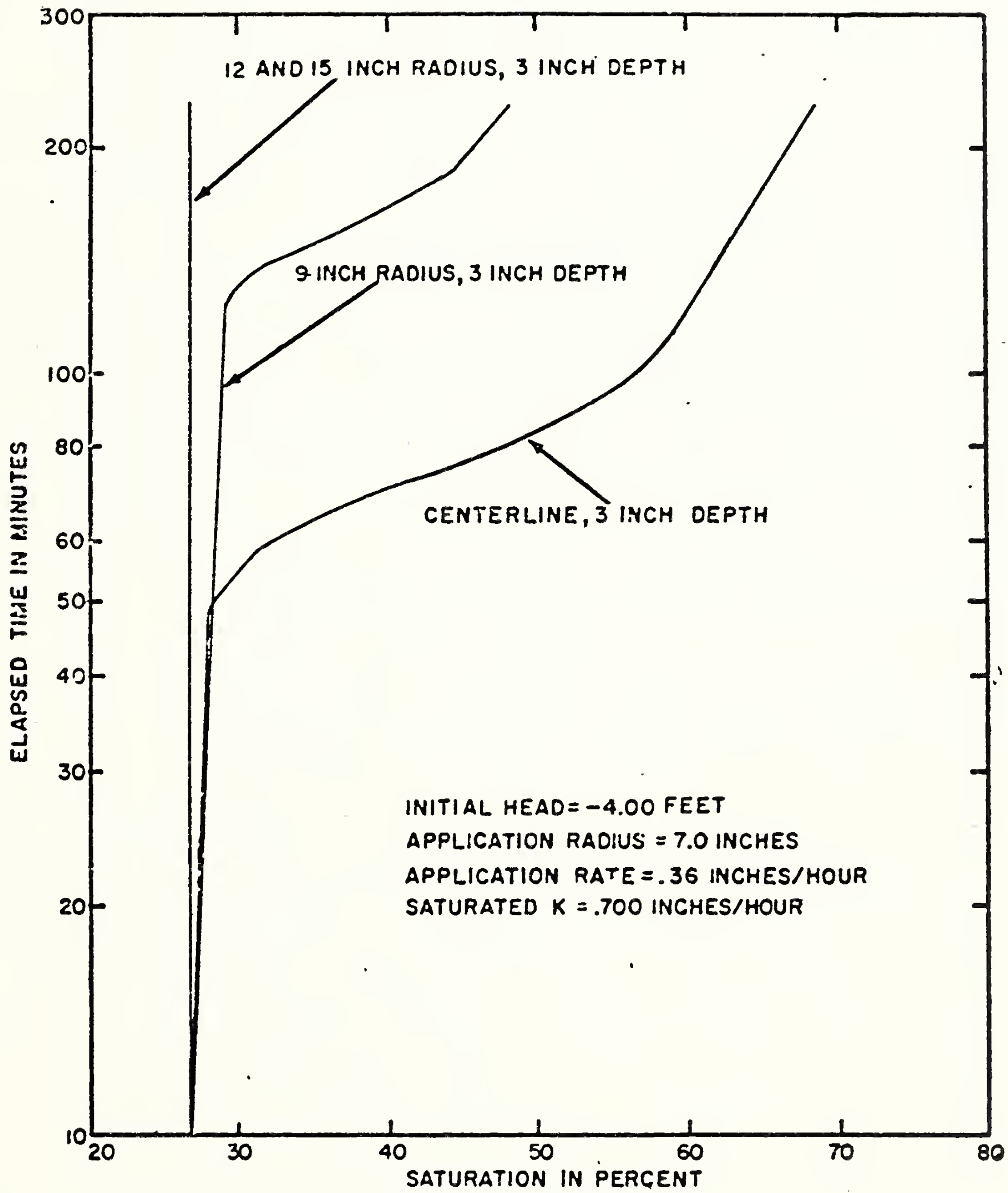

Figure 12. Predicted effect of lateral spreading from a circular infiltrometer at a depth of 3 inches.

CRIS Work Unit No.: SWC-011-fBo-1 Code No. Ida-Bo-106.1

Title: Natural evaporation from sagebrush rangelands, alfalfa, and stock ponds in a semiarid environment.

Location: Northwest Watershed Research Center, Boise, Idaho.

Cooperation: The University of Idaho will furnish a portable micrometeorological instrument trailer for initial acquisition of data at study sites in the Reynolds Creek Experimental Watershed.

Personnel: L. M. Cox and W. R. Hamon; G. H. Belt, University of Idaho, School of Forestry

Date of Initiation: November, 1968.

Expected Termination: November, 1973

Objectives:

1. To determine the evaporative loss of water from sagebrush rangelands, irrigated alfalfa, and stock ponds while observing pertinent meteorological parameters and the soil moisture status.

2. For predictive purposes to develop relationships for associating the evaporative loss with meteorological parameters, type and degree of surface cover, soil moisture, and potential evaporative demand.

Need for Study:

The water and attendant sediment yielded from a watershed or land area represents a balance between that entering the area as precipitation, that stored, and that lost through the processes of evaporation and transpiration. For semiarid, sagebrush rangelands, as represented by 50 million acres in the Northwest, the percentage of available water lost to evapotranspiration is around 95 percent where the yearly precipitation is near 10 inches. At higher elevations with annual precipitation of 30-35 inches, and where the major portion of precipitation occurs as snow, as little as 50 percent of the total available water is lost to evapotranspiration.

In the extremely low precipitation areas there is need to conserve all the moisture and provide as dense a cover as possible to prevent excessive erosion when convective rainstorms occur. The August storms of 1968, produced 2 to 3 inches of precipitation and sediment yields of 2 to 5 tons per acre on such lands. In higher precipitation areas, a potential exists for improving management and increasing forage yields for a greater site utilization of available water.

A predictive capability for the runoff and sediment that can be expected from rangelands is required by the Soil Conservation Service, the Bureau of Land Management, and land owners to carry out multiple-purpose management of these areas, and to optimize forage production, water yields, sediment reduction, wildlife protection, and recreational potential. A complete understanding of the evaporative process is essential for developing predictive relationships for the evapotranspiration component for definable soil-vegetation complexes under a particular level of management.

A capability of measuring and predicting the water lost by evapotranspiration is required to apply an infiltration model in the prediction of the surface runoff component and resulting sediment yield from any land area. Improved management, based on a knowledge of available water and the physical factors controlling the amount of water lost to evapotranspiration, can reduce the sediment loss by possibly 50 percent in the 8- to 12-inch precipitation zone and possibly increased forage yields by as much as 80 percent in the 20 to 30-inch precipitation zone. Improved efficiency in the design of water retention structures will result from improved estimates of runoff and sediment since the estimates of soil-water storage will be improved with better information on evapotranspiration losses.

Design of Experiment and Procedures to be Followed:

The evaporation and evapotranspiration studies will be conducted in the outdoor hydrology laboratory of the Northwest Watershed Research Center--Reynolds Creek Experimental Watershed. Procedures for measuring and predicting evapotranspiration must cope with sparse vegetation cover, and unsaturated surfaces.

The primary measurements to be obtained in the field will be those concerning the various parameters contained in combination formulas for estimating evapotranspiration. (See 1968 Annual Report.) In addition, profiles of wind and temperature along with humidity at two levels for Bowen ratio calculations will be obtained. Specifically, the air temperature will be sensed at elevation z_o where the logarithmic wind profile extrapolates to $V = 0$.

The required meteorological data will be complemented by data on soil-heat storage; soil heat flux; soil moisture; type, height, and cover of vegetation; soil type; and percentage of rock pavement. The vegetation and soil data will be used for designating definable soil-vegetation units. The evaporative performance of these units as related to existing meteorological conditions will be used for specifying a predictive model.

The energy balance and Bowen ratio procedure using ΔT and Δe at two heights will be used to obtain independent measurements of evapotranspiration where applicable. Also, independent measurements of evapotranspiration will be made from soil moisture

determinations and from lysimeters. Soil moisture data will be obtained by neutron and gamma sensors from access tube networks on definable soil-vegetation complexes. Lysimeters of the hydraulic-weighing type have been installed at several study sites. These lysimeters consist of an inner tank (5 feet in diameter and 6 feet deep) of undisturbed soil that rests on a coil of 2-inch butyl tubing filled with liquid and housed in an outer tank. The butyl tubing is connected to a manometer or pressure transducer for monitoring pressure changes resulting from the loss or addition of water.

Preliminary data on temperature, humidity, and wind profiles and on energy components have been obtained as a cooperative endeavor with the Department of Forestry, University of Idaho. This cooperation will be continued to test measurement apparatus and sensors, and to obtain data for evaluating transfer coefficients for dry, sparsely vegetated areas.

Experimental Data and Observations:

Lysimeter Data

Lysimeter data were collected only from the Sheep Creek Study Site, and they were of marginal quality because of pressure recording problems.

The lysimeters in the irrigated alfalfa field were completely engulfed by a high water table because of a leak in the outer instrument tank.

The lysimeters at Reynolds Mountain required servicing following the winter, but late season snowdrifts made it impossible to move a crane to the site until late summer. Consequently, the high evaporative losses that occur during the spring season, when soil moisture is available, were not measured.

Soil Moisture Data

Soil moisture data collection, along with precipitation and runoff, was continued for the networks in the Summit, Sheep Creek, and the Reynolds Mountain study basins. Soil moisture data collection was concluded in Cummings Field (Ground-Water Study Basin). Information on these networks is contained in Table 2, p. 1-5. Additional soil moisture sites were installed during 1970 for use in studies under Research Outlines Ida-Bo-105.4 and 105.6.

All soil moisture data have been placed on cards for data handling and analysis.

Energy Budget Measurements

During the late spring of 1969, Dr. George Belt of the University of Idaho, obtained energy budget and meteorological data at three

sites in the Reynolds Creek Watershed as part of a cooperative study. Comments on these data were made in the 1969 Annual Report. The data were used during the past year in an analysis of evapotranspiration from sagebrush rangeland.

Comments, Interpretations and Future Plans:

Lysimeters

Temperature induced pressure fluctuations are still a problem in the pressure recording systems used for the soil lysimeters. Weekly data is about the best these systems are good for, and then only during periods when evaporative losses are high. Continuous pressure readings may be impossible without a.c.power.

A study is currently underway for testing the possibility of using a d.c. pressure transducer currently being used by snow research people. Consequently, the recording systems will be changed to weekly manometric measurements until this study is completed.

Soil Moisture

Soil moisture data collected since 1964 on the Summit, Sheep Creek, and Reynolds Mountain study basins will be analyzed during 1971 in connection with studies under Research Outline 105.4. The soil moisture data obtained as part of the study under Research Outline Ida-Bo-103.3 have been analyzed in assessing the water balance of an irrigated field. (Refer to this latter Outline for comment).

Watershed Evapotranspiration

Precipitation data obtained from dual precipitation gage sites (shielded and unshielded gages) have been used in a computational model to obtain realistic values of atmospheric precipitation. (See Research Outline Ida-Bo-102.1). Evapotranspiration, E.T., estimates for the water year of 1969-70 have been obtained for 4 sub-watersheds in the Reynolds Creek Watershed by use of the water balance equation, with storage changes, ΔS, neglected, as noted in Table 1.

From Table 1, the ratio of E.T. to computed precipitation, expressed as a percentage, ranged from 100% in the Summit basin to 67% in the higher elevation area of the Tollgate Watershed. Also, for the same areas, the evapotranspiration, expressed as a percentage of "potential" evapotranspiration, ranged from 27 to 67%.

As the above indicates, water balance computation can be made for watersheds to obtain yearly values of evapotranspiration for verification of independent procedures for estimating watershed evapotranspiration.

Table 1. Watershed evapotranspiration for the water year 1969-70.

Watershed and Elevation Range, Ft.	Precipitation (Computed)	Runoff	ΔS	E.T.	P.E.T.1/
	- - - - - - - - -	- Inches -	- - -	- - -	- - -
Summit (4180-4800)	10.00	0	0	10.00	37
Lower Sheep (5200-5428)	14.38	0.03	0	14.35	32
Salmon (3675-6200)	18.85	3.45	0	15.40	
Tollgate (4600-7300)	30.65	10.14	0	20.51	29

Evapotranspiration Estimates

The field data obtained by micro-meteorological instrumentation, as a cooperative effort with the University of Idaho, in the late spring of 1969 have been analyzed to obtain radiation balance estimates, and to compute evapotranspiration by the Bowen ratio method and by energy balance equations.

At the low sagebrush Sheep Creek site, under clear skies, the surface albedo was observed to be relatively constant at 18.0 ± 1 percent. Net radiation,, R_n, was found to be a linear function ($r = 0.99$) of incoming solar radiation, SWI, and can be expressed as:

$$R_n = 0.113 - 0.749\ SWI \tag{1}$$

where R_n and SWI are given in Ly./Min. On cloudy days a similar relationship exists, but there is more scatter in the data. Even so, R_n can be estimated with reasonable accuracy (± 0.03 Lys.) by use of equation 1. A close correlation was also found between the soil heat flux and net radiation. (Sample data are contained in a Research Report2/).

1/ P.E.T. represents potential evapotranspiration. Values extracted from 1968 Annual Report.

2/ Belt, G. H. Spring Evapotranspiration from Low Sagebrush Range in Southern Idaho. Research Project Technical Completion Report, Water Resources Research Institute, University of Idaho, Moscow, Idaho (October, 1970)

The relationship of evapotranspiration, LE, to net radiation, R_n, for the low sagebrush site where water was limiting yielde the regression equation

$$LE = 0.342\ R_n + 0.14 \qquad (2)$$

with an r value of 0.77 and standard error of estimate of 22 Ly./Day or approximately a 20-30 percent error.

Rates of evapotranspiration, E.T., on an average daily basis, at the Sheep Creek site during June, were estimated using the energy balance-Bowen ratio procedure. Average daily E.T. rates ranged from 0.05 to 0.12 inch under differing conditions of soil moisture and radiant energy supply. Latent energy flux accounted for 28-46 percent of net radiation during daylight hours. Soil heat flux was relatively constant, 11-15 percent of net radiation. On all but one of the 6 days of observations, more energy was partitioned into sensible heat than latent heat indicating that soil moisture availability, not energy availability, was the limiting factor during this period. This was true even though significant amounts of precipitation and overcast conditions occurred during the period of measurement.

Hourly variations in computed E.T. were the result of changes in the Bowen ratio. The magnitude of the ratio is determined by both vapor pressure and temperature gradients, the latter being the more variable. Variation in temperature gradients are correlated with mean wind velocity during overcast conditions, but are primarily determined by the net radiation flux during clear skies.

Comparison of Methods for Estimating Evapotranspiration on Semi-arid Lands in Idaho 3/

Micrometeorological data obtained from several sites in the Reynolds Creek Experimental Watershed have been used to evaluate various evapotranspiration (E.T.) formulas for applicability in the dry-land situation where non-saturated

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3/ Computations and analysis by Dr. George Belt, College of Forestry, University of Idaho.

soils dominate. Bowen ratio, energy balance-aerodynamic, and combination equations as presented by Tanner and Fuchs4/ and Fuchs, et. al.5/ have been used to obtain estimates of E.T. These equations are given below:

Bowen ratio

$$E_B = \frac{-(R_n - G)}{1 + \gamma \frac{(T_z - T_a)}{(e_z - e_a)}} \tag{1}$$

Energy balance

$$E_{EB} = -(R_n - G) + \rho c_p h (T_o - T_z) \tag{2}$$

Slatyer-McIlroy

$$E_{SM} = -[s/(s+\gamma)]\{(R_n - G) + (\rho c_p s) h[(e_z^* - e_z) - (e_o^* - e_o)]\} \tag{3}$$

Pot. E.T.

$$E_p = -[s/(s+\gamma)][(R_n - G) + (\rho c_p / s) h (e_z^* - e_z)] \tag{4}$$

Gen. Conbination

$$E_c = -[(\gamma + s)/s] E_p + (\rho c_p / s) h (e_o^* - e_z) \tag{5}$$

4/ Tanner, C. B. and Fuchs, M. 1968. Evaporation from unsaturated surfaces: A generalized combination method. Jour. of Geophys. Res. Vol. 73, No. 4. (February 15).

5/ Fuchs, M., Tanner, C. B., Thurtell, G. W., and Block, T. A. 1969. Evaporation from drying surfaces by the combination method. Agronomy Journal (Jan.-Feb.)

More detailed explanations of these formulas with list of symbols can be found in the referenced papers. Table 1 summarizes the data requirement of the estimating equations (equations 1, 2, 3, and 5) and the equation for potential evapotranspiration, equation 4.

Table 2

Method	Equation	V_z	V_a	e_o	e_a	e_z	T_o	T_a	T_z	h	R_n	G
Bowen ratio	(1)				x	x		x	x		x	x
Energy balance	(2)	x	x				x		x	x	x	x
S-M Combination	(3)	x	x	x		x	x		x	x	x	x
Potential E.T.	(4)	x	x			x			x	x	x	x
Gen. Combination	(5)	x	x			x	x		x	x	x	x

The exchange coefficient, h, is defined as:

$$h = k^2 V \left[\phi + \ln (z + D)/z_o\right]^{-2} \qquad (5)$$

where $\phi = f(R_i)$ and $R_i = f(T_o, T_z, V_a, V_z)$ (5a)

Primary differences in the data requirements for the estimating equations in Table 2 can be summarized as follows:

1. The Bowen ratio method requires measurement of vapor pressure at a second level, but not an evaluation of h.

2. The energy balance - aerodynamic method requires numerical evaluation of h, and surface temperature but no measurement of vapor pressure.

3. The Slatyer-McIlroy combination method requires Evaluation of h, surface temperature, and surface vapor pressure.

4. The generalized combination method requires a numerical evaluation of h and surface temperature.

The energy balance - aerodynamic and combination formulas require evaluation of h, by use of the KEYPS function. This procedure requires evaluation of temperature and velocity gradients, and calculation of the Richardson Number. In this study, T_o was obtained by statistically fitting the air temperature profile by assuming similarity with the wind profile.

By this method, the temperature, T_o, was obtained at height z_o where the wind velocity extrapolates to zero - not ground surface temperature as used by Tanner and Fuchs[2].

In Figures[6] 1, 2, and 3, E.T. estimates obtained by the energy balance and combination equations from an irrigated alfalfa field, a big sagebrush site, and a low sagebrush site are compared with those obtained by the Bowen ratio method. The graphs for the irrigated alfalfa field contain data obtained only under lapse conditions. The fewer data points from the irrigated site result from using data free of advective heat.

Differences between estimates appear to be the result of variations in data required by the several formulas coupled with experimental error. A significant point concerning the irrigated alfalfa data is the good agreement of the several estimating methods. The principal source of experimental error was in the measurement of the vapor pressure gradients. In the case of the irrigated field, vapor pressure gradients were substantially greater (approx. 0.2mb.) than at the other two sites. It is tentatively concluded that the more accurate measurement of vapor pressure resulted in the good agreement.

At both sagebrush sites, Figures 2 and 3, the Bowen ratio procedure yielded estimates of E.T. smaller in magnitude than the other methods. Greater scatter of points at these dry sites is also obvious. As stated above, this is probably due to the lesser accuracy in measuring vapor pressure gradients.

Errors in the exchange coefficient, h, are a potential source of bias explaining departure of E.T. estimates from the 1:1 line in Figures 2 and 3. Comparison of exchange coefficients can be made by use of the dimensionless coefficient K_B^*, defined as:

$$K_B^* = \frac{K_B}{\frac{d\bar{u}}{dz}(z - D)^2} \qquad (6)$$

where

$$K_B = \frac{H\,(Z_z - Z_a)}{(T_z - T_a)\,\rho\, c_p}$$

and H is calculated by the Bowen ratio method. Values of K_B^* were used to compare data from this study with the dimensionless form of the KEYPS exchange coefficient and similar coefficients

6/. Figures follow p. 10-11

obtained by Pruitt and Aston[7/] from the Davis lysimeter. These data plotted in Figure 4, although exhibiting considerable scatter, suggest that the exchange coefficients obtained from the KEYPS function, and used in equations 2, 3, and 5 are of reasonable magnitude. The lack of any systematic bias suggests that the coefficients are not responsible for the systematic differences between Bowen ratio E.T. estimates and estimates by equations using the transfer coefficient for the sparsely vegetated rangeland sites.

The estimating equations were evaluated assuming equality of exchange coefficients. Equation 1 assumes $K_H = K_E$ and 2, 3, and 5 assume $K_H = K_M$. While recognizing that other assumptions may be appropriate, particularly at the more unstable Richardson Number, R_i, neither the experimental results obtained nor the literature provide a satisfactory alternative assumption. Since the 1:1 relationship for the irrigated site is significantly better than those of the dry rangeland sites and since the absolute magnitude of the exchange coefficient appears appropriate, it appears that the magnitude of the vapor pressure gradient may have been under-estimated. Under-estimation of the vapor pressure gradient and/or inequality of exchange coefficients ($K_H = K_E$) appear at this writing to be the more probable explanation for the differences in E.T. estimates obtained.

The computed values of E.T., as obtained by the energy balance and combination methods, are essentially identical as demonstrated in Figures 1, 2, and 3. This signifies consistency in the data since the combination equations are simply disguised versions of the basic energy balance as represented by equation 2, obtained by use of identities contained vapor pressure terms. On examination of Table 1, it is readily apparent that the combination equations, equations 3 and 5, require data on vapor pressure in addition to the data needed for the energy balance, equation 2. Therefore, the only purpose for the Slatyer-McIlroy combination equation is to express the energy balance in terms of surface and air vapor pressure deficits so that an equation for potential evapotranspiration, equation 4, can be derived. It follows by a simple algebraic exercise that the only independent equation for computing evapotranspiration is the energy balance formula, equation 2.

7/ Pruitt, W. O., and Aston, M. J. Atmospheric and surface factors affected evapotranspiration. Chapt. 3, P. 69, in Brooks, F. A., et. al. 1963. Investigation of energy and mass transfers near the ground including the influences of soil-plant-atmosphere system. University of California, Davis, California. (Final Report. Task: 3A 99-27-005-08. AD 410-263.)

Future studies will be directed toward developing a useable energy balance equation, based on the resistance concept, for sparsely vegetated rangelands. Additional field data will be obtained to evaluate the air transport resistance and the internal resistance to flow of water by the soil and vegetation. An attempt will be made to relate the latter resistance to vegetation types and available soil moisture.

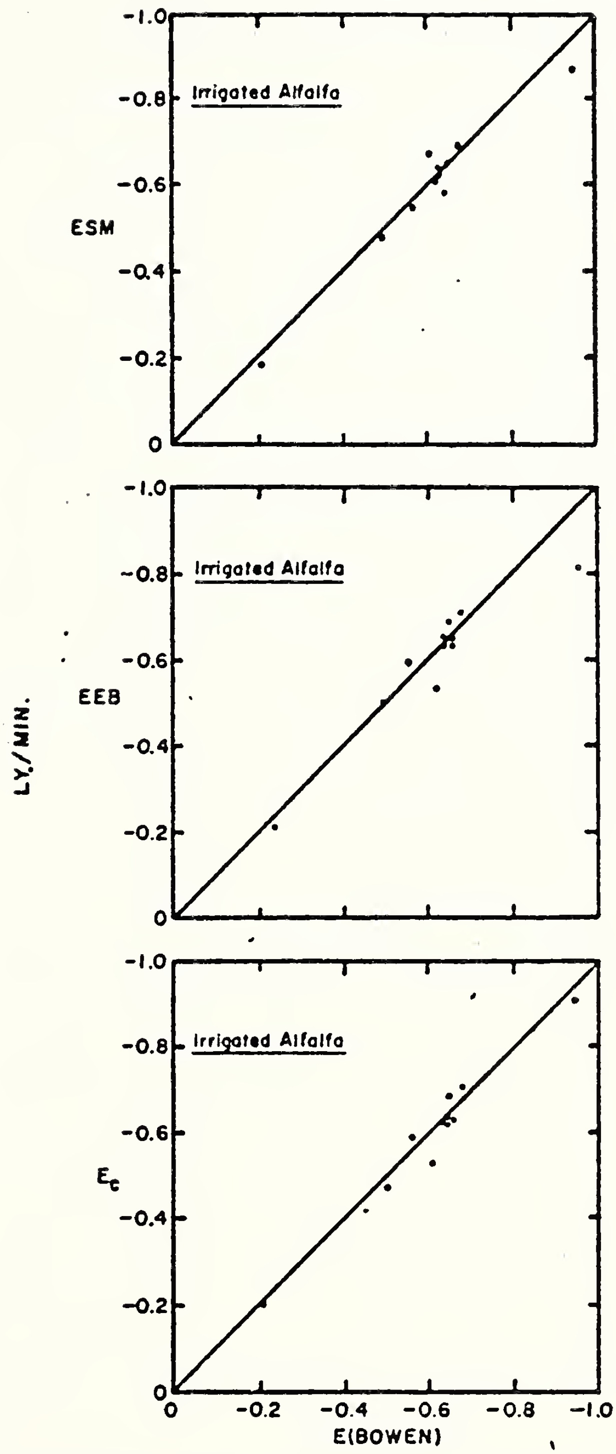

Figure 1. Evapotranspiration computed by different methods from selected 30-minute mean profile data.

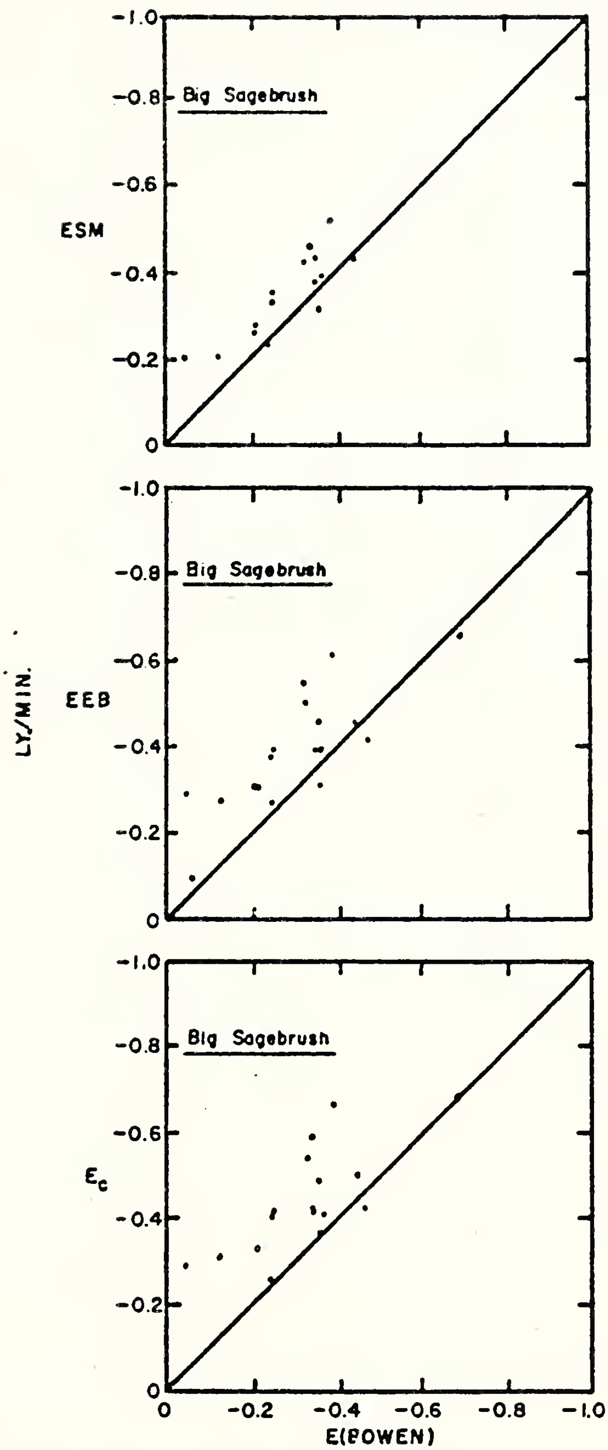

Figure 2. Evapotranspiration computed by different methods from selected 30-minute mean profile data.

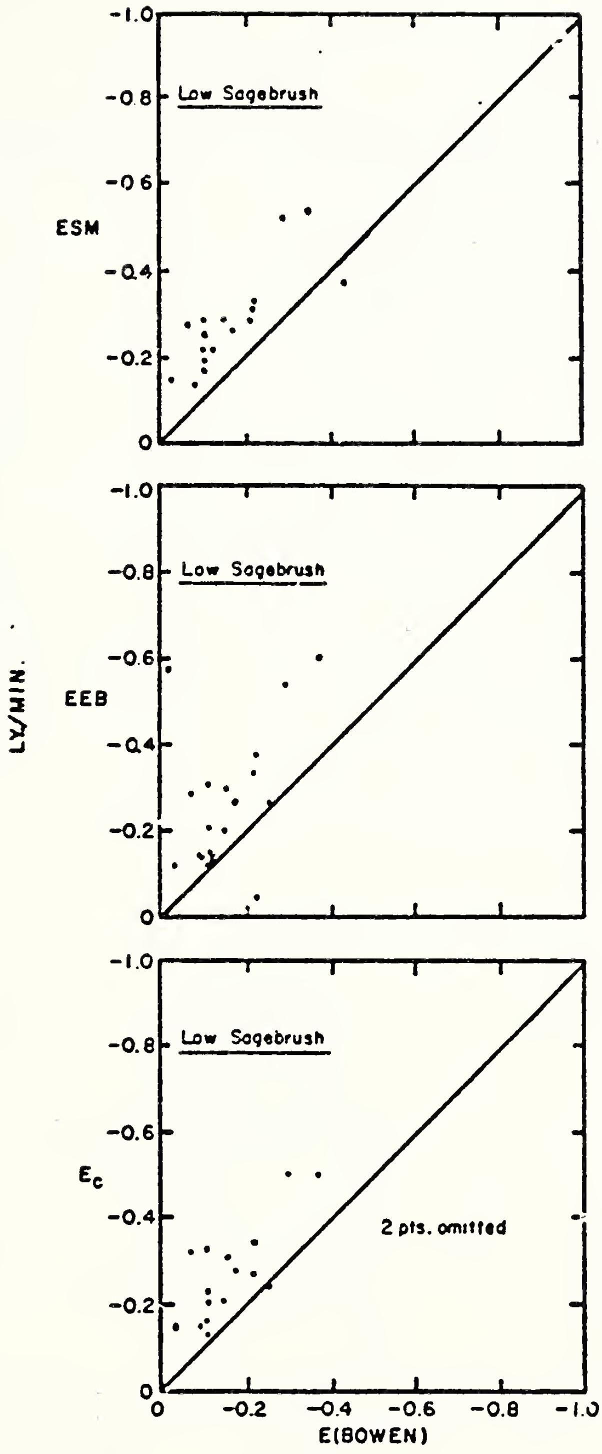

Figure 3. Evapotranspiration computed by different methods from selected 30-minute mean profile data.

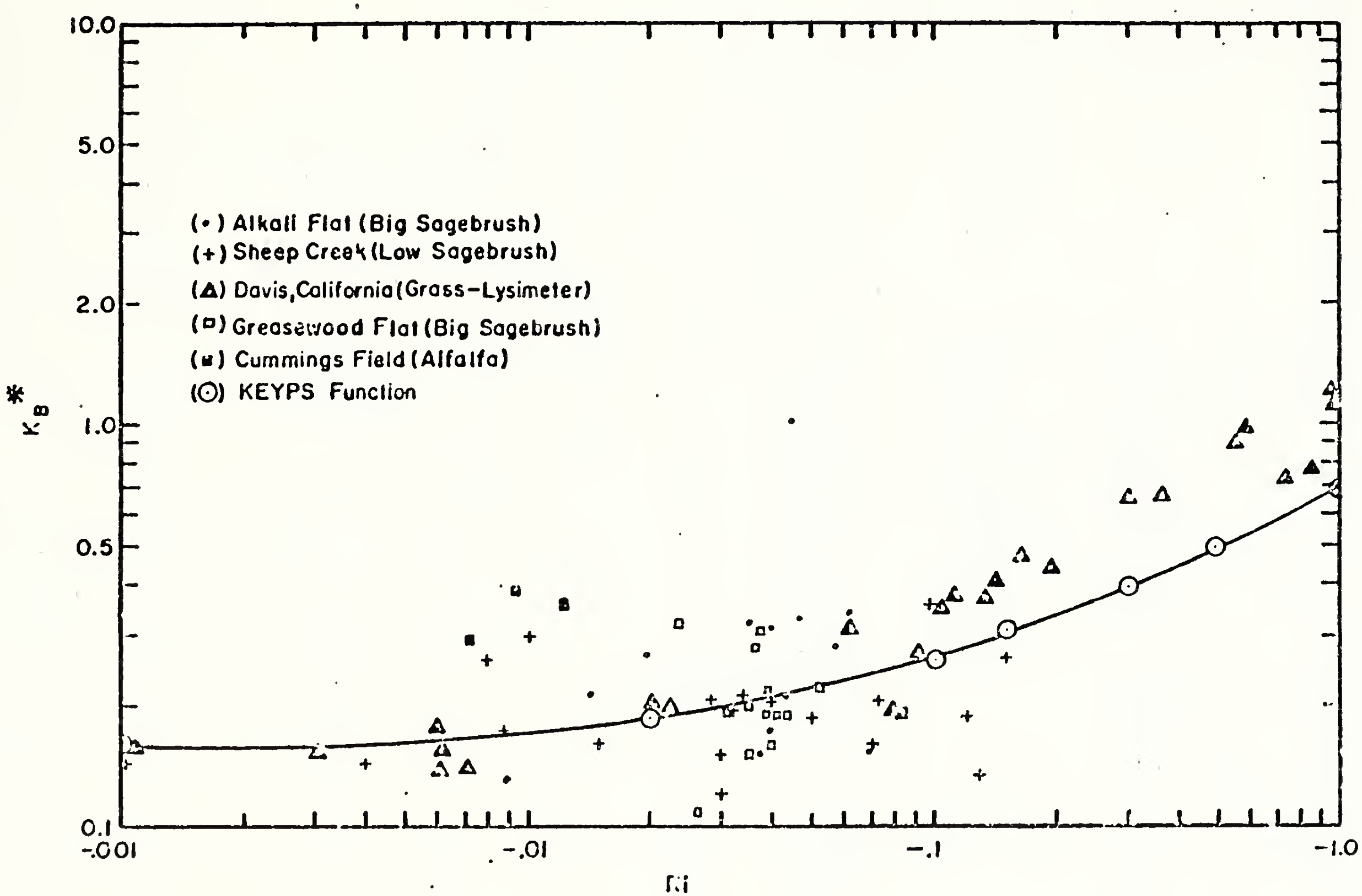

Figure 4. Dimensionless exchange coefficient, K_B^*, in relation to the Reynolds Number, R_i, as determined from evapotranspiration as obtained from lysimeters,[1] the Bowen Ratio Method, and by use of the KEYPS Function.

CRIS Work Unit No. SWC-012-fBo-2 | Code No. Ida-Bo-103.3

Title: Ground-water flow system under an irrigated field.

Location: Northwest Watershed Research Center, Boise, Idaho.

Personnel: G. R. Stephenson, and J. F. Zuzel, ARS-SWC; R. E. Williams, and D. W. Allman, University of Idaho.

Date of Initiation: July 1, 1967

Expected Termination: Originally planned, 1969. Recommendation, September 1971.

Objectives:

The ultimate goal is the evaluation of the contribution of ground water to streamflow in an area where ground-water flow is influenced by irrigation practices. The field study area will consist of an irrigated alfalfa field in the Reynolds Creek drainage basin. Specific objectives are as follows:

1. To evaluate the hydraulic properties of the materials underlying the irrigated field.

2. To delineate the hydrogeologic boundaries of the flow system affecting the irrigated area.

3. To evaluate the inflow and outflow of ground water across the boundaries of an irrigated field.

4. To conduct an empirical field analysis of the effect of different, specified irrigation practices on ground-water flow.

5. To construct a resistance-capacitance analog model to depict the variations in the ground-water flow system when evapotranspiration, irrigation practices, and boundary conditions for the flow system are varied.

Need for Study:

Evaluation of the hydrologic flow components in a watershed requires knowledge of the underground flow system. The water status for any area is dependent upon the integrated inflow and outflow.

A common water-use practice in mountainous watersheds is the diversion of water from streams for irrigation. The increased consumptive use (evapotranspiration) greatly affects the quantity of water yielded from these watersheds. A considerable portion of the diverted water in such irrigated areas is returned to the stream as both surface and underground flow.

A strict accounting of the water entering and leaving an irrigated area is necessary for development of procedures to predict the subsurface flows and the losses to evapotranspiration. Such prediction schemes when developed can be utilized in digital or analog models to evaluate the variations in the ground-water flow system when evapotranspiration and irrigation practices are altered.

Design of Experiment and Procedure to be Followed:

The field phase of the study will be conducted on a 62-acre irrigated field, Figure 1, in the Reynolds Creek Experimental Watershed. Instrumentation for collection of data will include a network of observation wells and piezometers at critical locations, a network of soil moisture access holes, Parshall flumes to measure input and output of surface water, a recording raingage, a hygrothermograph, a wind recorder, a net radiometer, and a lysimeter for independent evaluation of evapotranspiration.

Pumping and injection tests will be used to determine aquifer constants, and several recorders will be installed to monitor continuous variations in ground-water levels.

Semiweekly, weekly or biweekly collections of all data will be made during the year, being most intensified during the irrigation season.

Experimental Data and Observations:

Three years of soil moisture data, 1968-1970, were collected for this st[illegible] b[illegible] use of the neutron probe. These data are used in conjunction with changes in the water table for evaluation of total water losses. Measurements for this 3-year period were made at 22 installations, 16 of which extended well below the water table. When analyzing these data for each irrigation season, one phenomena consistently prevailed--soil moisture at specific levels within the saturated zone varied from site to site, as well as between levels of each site (Figure 1).1/ A systematic time variation was evident in that the values were lowest in June and highest in October. This systematic time variation permitted corrections to be made to yield constant soil water values for depths continually below the water table.

Several phenomena have been considered in an effort to explain the time-dependent soil moisture variation below the water table:

1. Changes in composition of the soil water.
2. Variation in the volume of gases trapped below the water table.
3. Confining pressure.
4. Exsolution and dissolution of dissolved gases.
5. Changes in the bulk density.
6. Equipment error as a result of temperature sensitivity.

Water loss determinations were completed using corrected soil water values and piezometer water level data at 13 sites throughout the 62 acre irrigated field. These loss values including specific yield and any transpiration losses by the alfalfa, are for a soil column extending from a depth of 10 inches to the water table. The aerial distribution of these calculated values indicates that the total water loss below 10 inches

1/ Figure follows page 11-7 .

is relatively larger in the alluvial soils as compared to those near the edges of the field which are shallow soils developed from bedded clays and silts.

This method of using the corrected soil moisture data and water level data is believed to be the most satisfactory method of computing the total water loss in situ.

The water loss information was used to evaluate daily losses due to evapotranspiration at each site in the study area adjacent to a soil moisture access tube. Losses in the upper portion of the soil profile, determined by gravimetric sampling, were included in the daily evapotranspiration loss. This method proved reasonable for the conditions that prevail.

The coefficient of horizontal permeability was evaluated using Hovorslev's (1952) method which considers the piezometer screen geometry and basic time lag. This method does not permit computation of the ratio of horizontal to vertical permeability.

Comments, Interpretations, and Future Plans:

A considerable amount of effort was put forth to try to explain the time-dependent soil moisture variation below the water table. These changes, as illustrated in Figure I, occur at individual levels at each site as well as between sites. Several factors were investigated:

1. Changes in composition of the soil water. The capture of thermal neutrons by such elements as cadmium, boron, lithium or chlorine, which may be present in the water, could cause yearly variations in the apparent soil moisture content. It is not known how much the concentration of these elements must vary in order to produce a change of 10 percent in the neutron count. However, the range of variation of the concentration must be reasonably large as there was no information found on this subject in the literature. From chemical analyses run to date, only chlorine of the above-mentioned elements was detected, and only in very minor amounts. At present the possibility of composition changes in the soil water does not appear to be the principal factor causing a time-dependent soil water change below the water table, although it is still a possibility.

2. Variation in the volume of gases trapped below the water table. A change in temperature of the ground water would cause volumetric changes of entrapped gases. However, an annual variation of 4°F at a depth of 15 feet produces variations of only 1 percent in the volume of a gas. Because of the lowest water table elevation in the late fall, soil temperature would most likely be highest at this time. This would result in a maximum volume of the gas and a minimum soil moisture content through the displacement of ground water by a gas. However, a maximum soil moisture content occurs during the late fall, the exact opposite of the expected result if temperature were affecting the volume of entrapped gases below the water table.

3. Confining pressure. The volume of entrapped gases below the water table would also vary with the confining pressure. The major factor affecting the confining pressure is the yearly variation in the water table. A maximum elevation of the water table would minimize the volume of any dissolved gases and would consequently result in a maximum soil moisture content. However, a minimum soil moisture content occurs in June, even at depths which were continually below the water table for several years. Another fact which tends to discount a significant volume change of dissolved gases because of changes in the confining pressure is the lack of an abrupt change in the soil moisture content during irrigation. It was concluded that changes in the volume of entrapped gases caused by a change in the confining pressure were unable to account for the observed soil moisture changes below the water table.

4. Exsolution and dissolution of dissolved gases. Another possible phenomenon that must be considered to explain the changes in soil moisture below the water table with the passage of time is the exsolution and dissolution of dissolved gas from the water. A maximum temperature and a minimum confining pressure both occur in December. These two factors would favor the exsolution of any gases dissolved in the ground water. Thus, a maximum volume of gas exsolving from the ground water would have accumulated by December. A maximum volume of gas should coincide with the minimum percent of soil moisture by volume. With the minimum soil moisture values occurring in June, exsolution of dissolved gases from the ground water is not a satisfactory explanation for the increase in the percent soil moisture by volume below the water table.

   The evidence gathered to date does not indicate that dissolution is the primary factor causing the cyclical variation in the percent soil moisture by volume below the water table with the passage of time. The water table has not declined to an elevation sufficiently low enough to allow the entire soil column penetrated by the soil moisture access tube to become partially drained. Partial drainage is necessary if dissolution of entrapped gases is to account for the observed changes in the percent soil water by volume below the water table with the passage of time. For example, the water table declined to only 11.0 feet below the soil surface at soil moisture access tube site 822 during the period from April to December 1969. Soil moisture determinations were made to depths of 17.3 feet below the soil surface. Other piezometers indicate that the water table rose approximately 2.5 feet from December 1968 to April 1969. It is quite probable that a portion of soil moisture access tube 822 remained below the water table for 1 or more years. It would not be likely that the partially drained soil and the soil below the lowest water table attained would have the same percent by volume of entrapped gases. Thus, the soil above and below the lowest water table attained should behave in a different manner. Vertical soil moisture profiles do not reveal any abrupt change in the behavior of the percent soil moisture by volume with the passage of time in the vertical direction. It was concluded that the dissolution of entrapped gases could not account for the observed changes in the percent soil moisture by volume with the passage of time for depths that were continually below the water table.

5. Changes in bulk density. Yearly fluctuations in the water table could cause changes in the soil bulk density with a variation in the vertical stress. Since the actual compression of the soil was very small compared to the apparent soil water variation, changes in the bulk density were discounted as being capable of significantly affecting the soil moisture content below the water table.

6. Equipment error as a result of temperature sensitivity. The effect of daily ambient air temperature on the scalers and rate meter has also been considered as a possible phenomenon causing the variation of the apparent soil moisture content below the water table. This study is still progressing, but it does appear as though the rate meter and possibly the two scalers are temperature sensitive. One problem with the data is that no record was made of the scaler used to collect the data. At present, the temperature sensitivity of the scalers and rate meter appears to be the most probable factor causing a time-dependent soil moisture change below the water table.

The variations in percent volume soil water may seem insignificant for most uses of soil water information. However, for this particular study, soil water values were used to assess specific yield and evapotranspiration to compute water losses from the irrigated field. In comparing the corrected data with the uncorrected data, the differences are significant. Using the uncorrected data, the water loss determinations, including specific yield and transpiration, had a logarithmic mean of 10.4 percent. When using the corrected soil water data, the water loss values were 23 percent, which is reasonably close to the average water loss of 25 percent for loam soils based on estimated porosity and field capacity data (Israelson and Hanson, 1967, pp. 411). The water yield values calculated from soil moisture and water level data are for a soil column extending from a depth of 10 inches to the water table.

The soil water losses in the upper 10 inches of the soil were determined by repeated gravimetric samples at 4 sites within the field. Linear regressions on the resulting plots of soil moisture against time indicated that the greatest rates of soil water loss from the upper 10 inches of the soil decrease from an average of 0.044 in./day in the upper field to 0.017 in./day in the lower field, which is finer textured than the upper field. These rates are appliable from May 30, two days after significant rainfall ceased until the estimated permanent wilting point was attained during the period from July 18 to August 2, 1969. Any soil moisture losses from the upper 10 inches of the soil attributable to evapotranspiration or gravity drainage was measured gravimetrically.

An estimate of the long term effects such as ground-water outflow on the water level declines for each shallow piezometer located within the irrigated field were based on the assumption that evapotranspiration was negligible immediately following the cutting of the alfalfa. First or second order regressions were fitted through a plot of the daily water level declines beginning immediately following the cutting of the alfalfa and terminating about two weeks after the cutting of the alfalfa. These equations were then used to calculate the net long term effects on daily water level changes at the site when the first crop was cut. This procedure was repeated for the

second crop cutting in August. These two data points and the water level data in the fall following the growing season were used to construct an equation defining the net long term effects on piezometer water level changes at the site throughout the period of study. The net result of long term effects such as ground-water inflow or outflow at the piezometer sites was measured during periods when evapotranspiration was assumed to be negligible. It is believed that the long term effects are caused primarily by the ground-water flow system with the long term effects primarily providing an estimate ofthe change in the water level at a site.

The daily losses due to evapotranspiration at each site adjacent to a soil moisture access tube were evaluated by subtracting the daily water level decline caused by long-term effects from the observed daily ground-water decline and multiplying the remainder by the appropriate water loss factor. The water loss due to gravimetric soil moisture loss in the upper 10 inches was also included in the daily evapotranspiration loss. Preliminary results indicate daily evapotranspiration losses up to 0.38 in./day during very windy hot conditions with a mature crop. The daily evapotranspiration appears to vary aerially in a manner dependent upon wind direction, andvelocity. This method of estimating daily evapotranspiration results in values which are reasonable for the field conditions.

The evapotranspiration water losses for two hourly intervals between June 19 and July 13, 1969, were calculated using the daily evapotranspiration water losses. The two hourly changes in the piezometer water levels were corrected for changes in the barometric pressure. The barometric efficiencies of the piezometers were approximately 5 percent. Piezometer time lags and amplitud ratios (Hvorslev 1952) are satisfactory for measuring two hourly changes in the fluid potential of water adjacent to the piezometer screen. The largest basic time lag for a piezometer equipped with a continuous water level recorder was 7.4 min., which would result in an equalization ratio of 90 percent in 17 min. following a change in the fluid potential of the water adjacent to the well screen. Since all the piezometer-soil moisture sites did not receive their final irrigation at the same time, and particularly the lysimeter site which received its last irrigation on May 20 as compared to June 11 for the surrounding field, adjustments were made to the daily gravimetric and ground-water losses occurring below a depth of 10 inches. Final calculations of the two hourly evapotranspiration losses have not been completed at this time. The two hourly evapotranspiration water losses appear to have much larger relative errors associated with them because piezometer time lags and barometric efficiancies must be taken into account.

The coefficient of horizontal permeability was evaluated using Hvorslev's (1952) method which uses piezometer screen geometry and basic time lag. The population frequency distributions for permeability are all log normal. It is not possible to determine the ratio of the coefficient of vertical to horizontal permeability using Hvorslev's technique. The mean permeability for the alluvium assuming K_H/K_z = 1.0, 10, and 100 are 1.57 gal./d./ft.^{2}, 2.11 gal./d./ft.^{2}, and 2.66 gal./d./ft.^{2} respectively. The mean permeability for the Beston Ranch Unit underlying the alluvium assuming K_H/K_z = 1.0, 10, and 100 are 0.518 gal./d./ft.^{2} 0.690 gal./d./ft.^{2} and 0.863 gal./d./ft.^{2} respectively. Even though it was assumed the K_H/K_z = 10, the effect of this assumption on the resulting mean horizontal permeability is rather small

since the method is rather insensitive to changes in the vertical permeability. The coefficients of permeability will be evaluated by applying other methods to the slug test and injection test data. However, initial results indicate that the permeability of the materials underlying the irrigated field is rather low, which will result in low ground-water losses or gains due to the ground-water flow system.

Final results of this work will be forthcoming in several publications, the first of which is scheduled for summer 1971. The only additional work remaining, other than final analysis of the data, is to check out the validity of the permeability tests and possibly run a few more.

References Cited:

Hvorslev, M. J. 1951. Time lag and soil permeability in ground-water observations Waterways Experiment Station, Corps of Engineers, U.S. Army Bul. No. 36, April.

Israelsen, O. W., and Hansen, V. E. 1967. Irrigation principles and practices. John Wiley and Sons, Inc., NY, NY.

aside the scheme is rather insensitive to changes in the vertical anisotropy. The relative role of permeability will be evaluated in analyzing other methods of pumping test and infiltration rate data. However, general results indicate that some permeability of the materials underlying the [illegible] is acting [illegible] with the low groundwater losses or gains [illegible] ground water flow system.

Final results of this work will be forthcoming in several publications, the first of which is scheduled for summer 1971. The only [illegible] until then, other than final analysis of the data, is to check out the accuracy of the permeability tests and possibly [illegible] the work.

References Cited

Hvorslev, M. J. 1951. Time lag and soil permeability in ground-water observations. Waterways Experiment Station, Corps of Engineers, U.S. Army, Bull. No. 36, April.

Israelsen, O. W., and Hansen, V. E. 1967. Irrigation principles and practices. John Wiley and Sons, Inc., NY, NY.

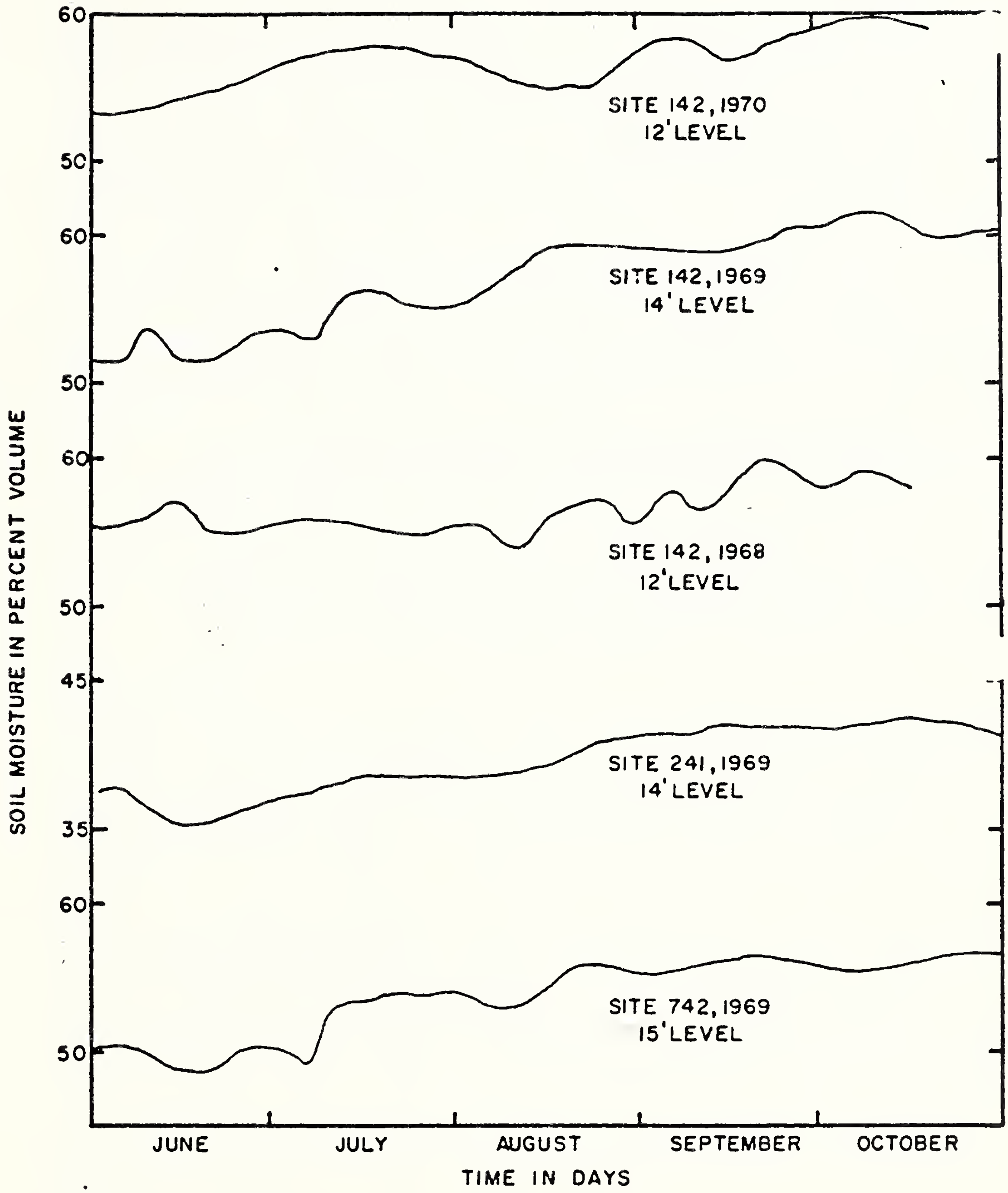

Figure 1. Variations in percent volume soil moisture at depths below the water table at selected sites. (Sites 142 and 742 located in clay soils; 241 located in alluvial soils.)

CRIS Work Unit No. SWC-012-fBo-2 Code No.: Ida.-Bo-103.4

Title: Geochemistry of ground-water flow systems.

Location: Northwest Watershed Research Center, Boise Idaho.

Personnel: G. R. Stephenson and John Zuzel; Dr. J. V. A. Sharp, University of Nevada.

Date of Initiation: January 1968. Expected Duration: January 1971.

Objectives:

1. Development of chemically oriented methods for determining flow characteristics of ground-water systems of western rangelands.

2. A better understanding of the changes in water chemistry which occur within such systems, primarily as the result of reactions between water and geologic materials.

Need for Study:

Dissolved constituents of natural waters result from combined reactions of water, soil, and rock, and to a varying extent from man's wastes. In general, information is needed on the origin and occurrence of dissolved constituents within a flow system and the full significance of each portion of the system in mobilizing and transporting these constituents.

There is a definite need for improvement in the knowledge of the chemistry of ground water in flow systems associated with western rangelands. Chemical parameters offer possibilities as effective tools in unraveling some of the more perplexing hydrologic problems heretofore not subject to unique solution by conventional hydrologic methods. Problems possibly amenable to improved solution by geochemical methods include (1) age, amount, and residence time of ground water; (2) mixing of water from different sources; (3) definition of areas of recharge, lateral flow, and discharge; and (4) amount and location of recharge and discharge.

Man's imposition of a variety of management conditions on rangelands not only upsets long-term hydrologic relationships, but also disturbs long-standing geochemical relationships, causing changes in water quality which promise to accelerate over the years ahead.

Design of Experiment and Procedure to be Followed:

Field Phase: It will be necessary to perform a complete hydrologic analysis of the flow system(s) under investigation. This will require assembling all available hydrologic and geologic data, continued collection of ground-water data (water levels), possibly some expansion of present well networks, and installation of flumes and/or weirs at springs. Water samples for analysis will be collected periodically at wells and springs, probably on a monthly basis. Samples of precipitation and of soil water for analysis will be collected, using special rain gages and lysimeters. Flow-measuring devices will be placed at the outlets of springs. Some chemical dye tracer tests and artificial infiltration studies may be performed. Soil and bedrock samples will be collected at various places for analysis and laboratory studies.

Laboratory Phase: Water samples will be analyzed for common chemical constituents and, in some instances, trace elements. Some samples will be analyzed for isotopic constituents. Some soil and rock samples will be analyzed chemically and mineralogically. Column or batch equilibrations will be made of water and soils/rocks to observe chemical reactions which may be occurring in the system(s).

Experimental Data and Observations:

A sufficient number of water chemistry analyses, over a suitable time span, permits statistical analyses of this data to be performed with a high level of significance. The relationships tested were positions in the flow system as indicated by potential surface elevation and variation in ionic ratios throughout the basalt ground-water flow system. Analyses for the sedimentary aquifer system, and several local flow systems, have not been evaluated so no attempt will be made to comment on their significance.

A correlation matrix was computed correlating water-level elevation with various ionic ratios which occur in the water samples. The table of correlation coefficients and the variables are given in Table 1.

Table I points up several items of importance concerning the water chemistry of the basalt ground-water flow system. Silica (SiO_2) correlates positively. This means that progressing downstream in the flow system, the total percent of silica in the system decreases. From previous year's analyses, silica was always higher in the basaltic waters than in the waters of the sediment aquifers, and was considered to be an indicator to identify one system from another. However, the full significance of the presence of silica and its variation was not understood.

TABLE 1.--Correlation coefficients of variables versus water-level elevation.

Variable	Water Level Elevation
Water Level Elevation	1.000
Total Equivalents Per Million	-0.[illegible]
Total Anions + Total Cations/ SiO_2	-0.917
Ca + Mg/Na + K	-0.039
Total Alkalinity /Cl + SO_4	-0.428
Total Dissolved Solids	-0.319
SiO_2	0.088

* No. of cases = 75 for each Variable

All the other variables considered in Table 1 show a negative correlation with potential surface elevation, indicating a general increase in ionic concentration downstream in the flow system. This has been previously mentioned but can now be verified with the 1970 sampling and analysis.

Figure 1 shows an average hydrograph of the potential surface of four representative wells in the basalt flow system from 1967 through 1970. The average changes in the ionic ratio of total anions + total cations (TDS) / SiO_2, determined from 75 cases, is plotted above the hydrograph in this figure. The effect recharge has on the changes in this ionic ratio is evidence when reviewing Figure 1. The lag time and the variation in the ionic ratio are dependent upon the intensity of the recharge event and the time of year. The relation of the recharge event and the related change in TDS/SiO_2 is indicated by the arrows in Figure 1. In 1969 a large recharge event was recorded. A drop from 10.75 to 8.00 was recorded in the ionic ratio. During the summer months the ionic concentrations increase and a summer or fall event, such as in September of 1969, influence the ionic ratios to a lesser degree because the dilution effect is less significant.

Figure 2 shows the relationship between position in the basalt flow system, as expressed by the elevation of the potential surface at each of four wells, and the ratio of total dissolved solids to silica.

Each point shown in the figure represents an average of 18 potential surface elevations and 18 ratios of total dissolved solids to silica at each well site.

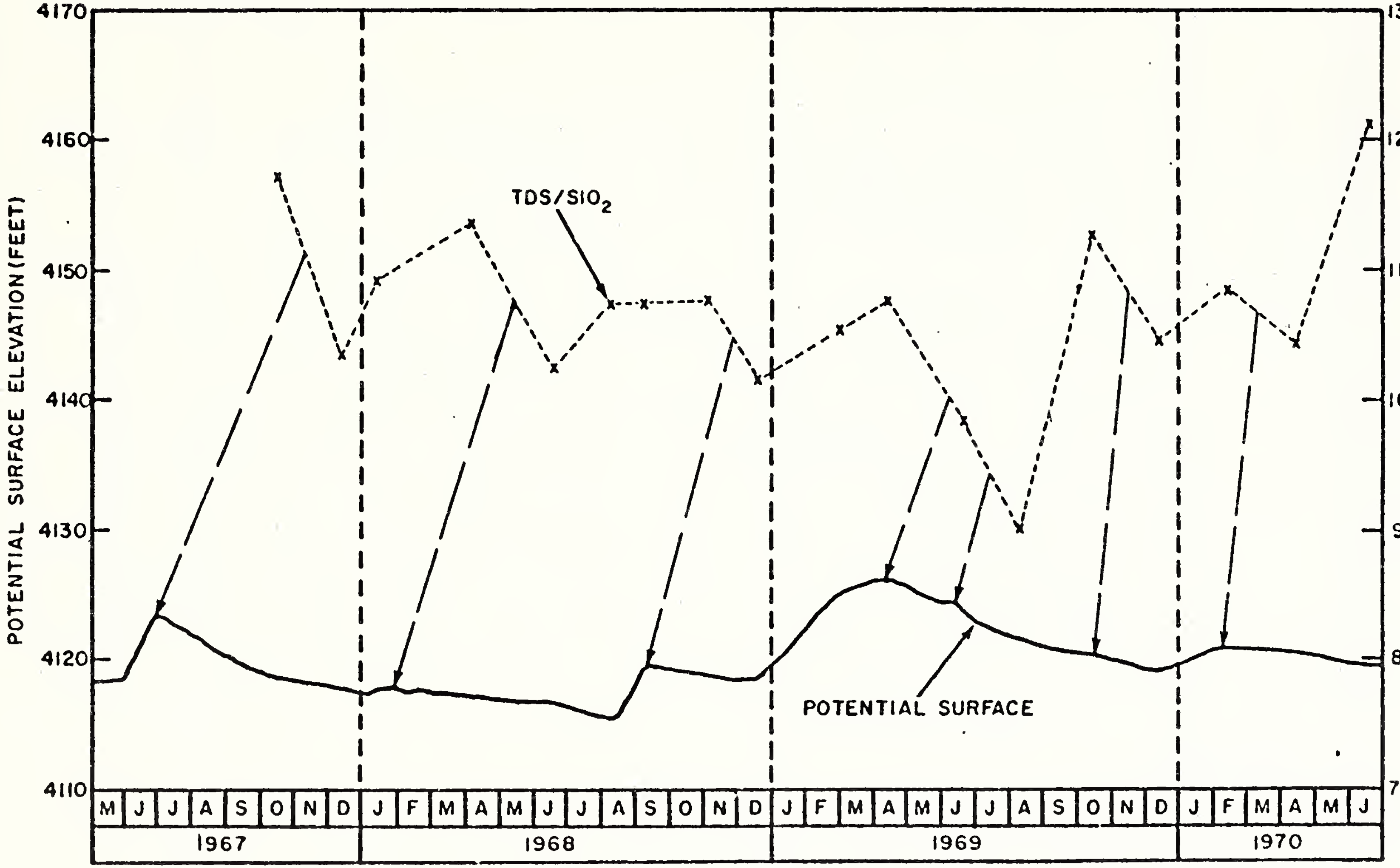

Figure 1. Potential surface hydrograph showing relation of recharge events to changes in ionic ratio of ground-water samples.

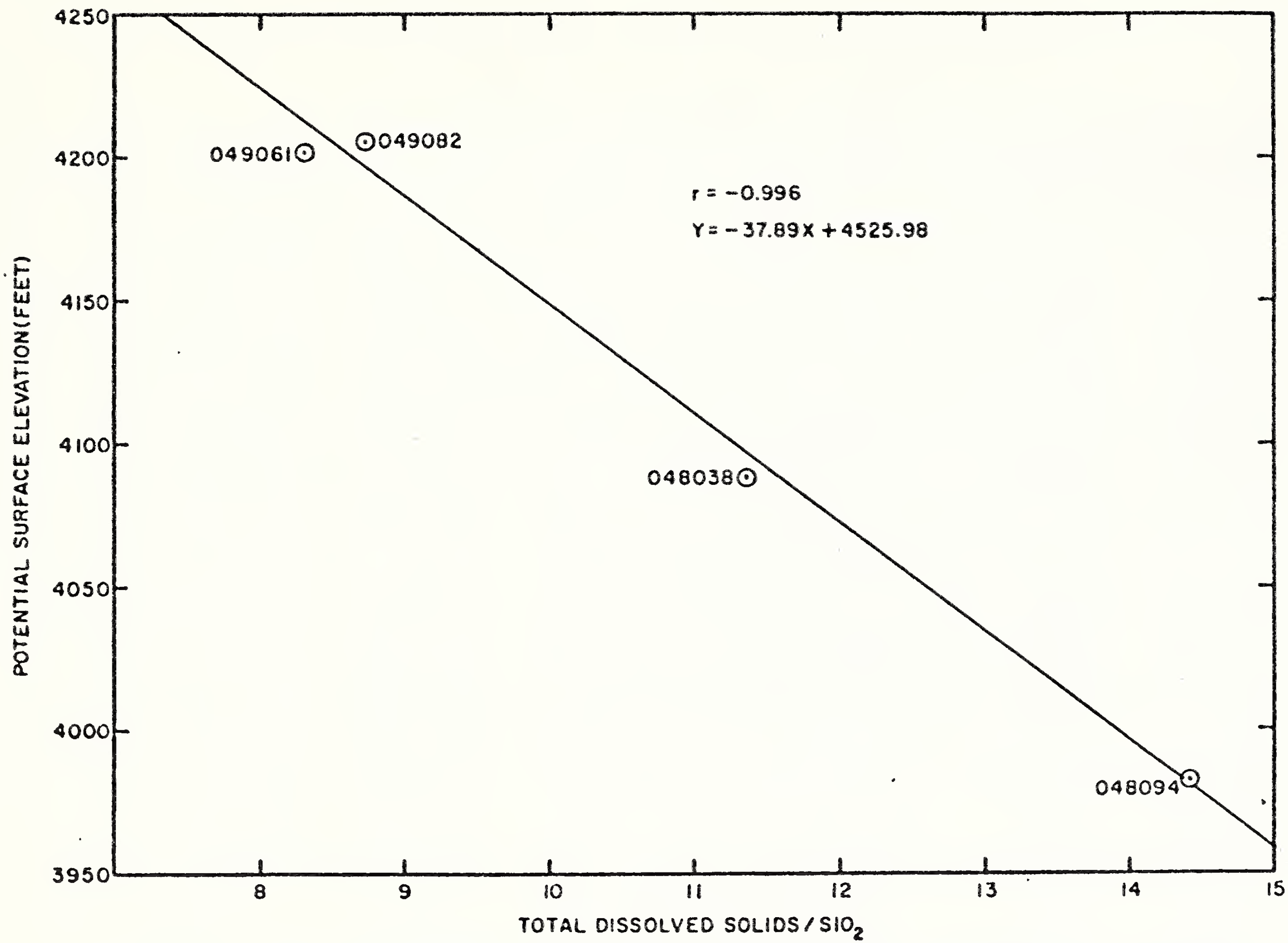

Figure 2. Regression showing relation of ratio of TDS/SiO_2 to position in ground-water flow system.

The high degree of negative correlation (-0.996) indicates that as one proceeds downstream in the basalt flow system, the ratio of total dissolved solids increases while silica content decreases resulting in a predictable increase in the ratio of total dissolved solids to silica.

While total dissolved solids versus elevation and silica content versus elevation both produce statistically significant correlation coefficients, these relationships are much less clear than when the ratio of total dissolved solids to silica is used in the correlation.

Comments, Interpretations, and Future Plans:

From the present correlation results, SiO_2 shows considerable instability. It varies from one sample site to another because of the presence or lack of secondary silica deposits which occur mostly in the upper portions of the flow system. The correlation matrix of Table 1 shows that SiO_2 correlates positively. This means that progressing downstream in the flow system, the total percent of silica in the system decreases. This further explains Figure 2, which shows the ratio of TDS/SiO_2 changing downstream in the flow system. The decrease in the ratio is the result of the decrease in SiO_2. The reason for the decrease in SiO_2 is probably caused by diminishing source of secondary silica and increased dilution in that direction. However, the lower values for SiO_2 in the lower areas of the basaltic aquifer system are still considerably higher than in the flow system in the lacustrine sediments.

When water chemistry information from other wells in the basaltic ground-water flow system is analyzed and plotted, as described above, and if the results fall within the limits of the regression of Figure 2, a method has then been found to locate positions within a flow system. This would be very beneficial in water quality mapping.

One well from which water chemistry information was obtained for a short record of time was used to test the above hypothesis. Data from this well, when plotted as water level elevation against the ratio of TDS/SiO_2, fell well within the limits of the regression equation of Figure 2. One test is not significant, but tests are now being run to try to develop this work further by using water chemistry data already gathered for wells in the sediments and from local flow systems. Additional samples from wells in the basalt ground-water flow system will also be analyzed. The plan is to develop a family of curves like the one on Figure 2, for the flow systems in the lacustrine sediments, local flow systems, and the basalt.

CRIS Work Unit No.: SWC-014-fBo-3 Code No. Ida-Bo-107.1

Title: Sediment yield from rangeland watersheds.

Location: Northwest Watershed Research Center, Boise, Idaho.

Personnel: C. W. Johnson, D. L. Schreiber, G. R. Stephenson, W. R. Hamon, G. A. Schumaker

Date of Initiation: September 1, 1969

Expected Duration: Originally planned - December 1974
Present recommendation - December 1974

Objectives:

1. To determine the relationships between sediment yield and variables describing hydraulic and hydrologic factors, and site and watershed characteristics which influence sediment yield.

2. To formulate a sediment yield prediction procedure for rangeland watersheds in the Northwest.

Need for Study:

Information on sediment yield is almost entirely lacking for millions of acres of predominantly sagebrush rangeland under Government land management and private ownership in the Northwest United States. There is a growing concern for soil losses from intensively-grazed rangelands, sediment damage to reservoirs, and erosion of stream channels.

Most rangeland watersheds in the intermountain Northwest have large areas of relatively steep hillslope topography and these areas need to be delineated for treatment to reduce erosion. Also, sediment yield information is needed for evaluating the benefits of watershed management and land treatment programs of the Bureau of Land Management and Soil Conservation Service.

Range sites found in the Reynolds Creek Experimental Watershed represent a large percentage of the rangeland in the Northwest and studies of sediment yield are essential for the development of sound management practices and in planning appropriate multiple use of these lands. Good land management decisions require information on how vegetative changes, fencing and land use alters the sediment yield potential of rangeland watersheds. The sources and quantities of these sediments need to be determined and measured so that research data can be used to predict sediment yield for ungaged areas in terms of available information on soils, climate, physiography and use. Research is also needed to adapt the universal erosion equation to rangelands.

Design of Experiment and Procedures to be Followed:

Suspended and bedload sediment yield from plots, channels and watersheds will be measured by use of pumping sediment samplers, splitting devices, catchments and hand sampling. Scour and fill within designated reaches of channels will be measured by photogrammetric techniques utilizing captive balloons or helicopters for obtaining photographs.

Runoff hydrographs from plots and watersheds will be measured through flumes, weirs, or in tanks to obtain data for computation of hydraulic parameters. The effects of precipitation impact and splash on soil erosion and overland flow will be studied using 14 ft. by 72 ft. plots and simulated rainfall. Critical velocity and depth of flow which influence erosion for particular soil and slope conditions will also be determined from plots. Plots, microwatersheds and watersheds will be located on various soil types in different precipitation zones. A wide range of slope length, slope area, aspect and relief ratio will be represented.

Erodibility of watershed soils will be determined from rainfall simulator plots to determine the effect of parent material, and soil texture, structure, aggregation, organic matter, and pH on soil movement. Large-scale soil movement will be traced with colored or tagged particles.

Data on vegetative, litter, and rock cover will be obtained from a related research outline where the procedure will be described in detail.

Physiographic and geomorphic factors will be determined throughout the Reynolds Creek Watershed. Detailed determinations of aspect and percent slope will be made by use of a systematic grid and a data reduction program. Hypsometric (area-altitude) information obtained for the study sites will be used to designate other areas of corresponding sediment production potential. Geomorphic factors will be related to sediment yield measurements.

Rainfall intensity and duration data are available from a network of precipitation gages and snow data are available from snow courses, snow pillow sites and other snow-measuring sites. Research Outlines Nos. 100.1 and 102.1 describe the instrumentation and procedure.

Evaluation of management and land use factors will be accomplished by selection of watersheds in areas with the same management and then fencing off one- to three-acre areas to exclude livestock and establish maximum vegetative cover.

Experimental Data and Observations:

1. Overland Flow Hydraulic Parameter Study

To study surface runoff and associated hydraulic parameters (velocity, depth, roughness, type of flow) which influence sediment yield, a laboratory study was conducted by D. L. Schreiber in cooperation with the ARS Erosion

Laboratory at the Palouse Conservation Field Station, Pullman, Washington. (CRIS Work Unit No.: SWC-016-fPul-1; Research Outline No.: Wash. Pn-66-15, terminated June, 1970.)

A mathematical model was developed to simulate and predict overland flow hydrographs. The kinematic form of the nonlinear partial differential equations of unsteady, spatially varied, open-channel flow were solved simultaneously by numerical integration. The mathematical model was verified by laboratory data obtained in the Erosion Laboratory Rain Tower.

Since surface roughness is practically impossible to measure quantitatively, parameter optimization was used in conjunction with the mathematical model to provide a set of representative, synthetic, laminar-flow resistance parameter values. Three different univariate optimization schemes were devised for this study. The first scheme produced "wholly optimized" hydrographs for which a single value of the resistance parameter can be used to describe the resistance to flow both during and after the occurrence of rainfall. The second scheme produced "two-piece optimized" hydrographs that were considered to be composed of two sections - during rainfall and after rainfall. An optimal value of the resistance parameter was determined for the rainfall section before the recession-section resistance parameter was evaluated. The third scheme produced "sectionally optimized" hydrographs that were divided into sections or time intervals of either 10 or 12 seconds. The optimal resistance parameter value for each section was determined in succeeding order.

Results of the three optimization schemes were compared to determine the sensitivity needed to describe adequately the resistance to laminar flow. Results of the third scheme, sectional optimization, were also used to provide synthetic data for use in an attempt to develop predictive equations for the laminar flow resistance parameter.

Detailed descriptions of the laboratory facilities and procedures, the experimental and synthesized data, and the development of the mathematical model and optimization schemes are contained in D. L. Schreiber's Ph.D. thesis, "Overland Flow Simulation by a Nonlinear Distributed Parameter Model," Washington State University, June 1970. Representative data and results are indicated below in Table 1 and in Figures 1-4. (All figures follow page 13-11).

2. Sediment Yield Studies

a. Sediment sampling equipment and facilities

Sediment facilities and a description of instrumentation operating in 1970 are listed in Table 2.

TABLE 1.--Optimal values of laminar-flow resistance parameter K for two-piece optimized hydrographs.

Test Number (1)	Slope, in feet per feet (2)	Intensity, in inches per hour (3)	Duration, in minutes (4)	K During Rainfall (5)	K After Rainfall (6)
10	0.0075	2.92	1.0	36	17
12	0.0075	3.11	4.0	29	18
19	0.0465	3.23	1.0	39	15
20	0.0465	2.84	4.0	35	17
24	0.0465	1.06	4.0	20	13
27	0.0806	2.97	1.0	34	13
29	0.0806	3.01	4.0	40	16
33	0.0806	1.20	4.0	25	14

TABLE 2.--Sedimentation facilities and instrumentation Northwest Watershed Research Center, 1970.

LOCATION DESIGNATION NO.	NAME	SEDIMENTATION INSTRUMENTATION	DESCRIPTION
036068	Outlet Weir	Hand Sampling	During Flood Events
046017	Salmon Cr. Drop-Box Weir	Hand Sampling	During Flood Events
046084	Macks Cr. Drop-Box Weir	P.S. 67 Pumping Sampler	Float Actuated
048077	Summit Drop-Box Weir	Gravity Sampler Bedload Catchment	Float Actuated Following Events
097098	Nancy Gulch Runoff Plot	Tanks and Splitter	Following Events
116083	Tollgate Drop-Box Weir	P.S. 67 Pumping Sampler	Float Actuated
138012	Upper Sheep Cr. Drop-Box Weir	Chickasha Pump Samp. Bedload Catchment	Float Actuated Following Events
166076	Reynolds Mtn. V-Notch Weir	Chickasha Pump Samp. Bedload Catchment	Float Actuated Following Events
015094	Little Rabbit Cr Drop-Box Weir	Chickasha Pumping Sampler	Float Actuated
022007	Rabbit Cr. Flume	P.S. 67 Pumping Sampler	Float Actuated

Hand sampling of suspended sediments at the large weirs during flood events continued through 1970; however, limited personnel and travel difficulties prevented collection of much valuable data at sites where pumping samplers were not installed or not in operation. Failures of the P.S. 67 pumping samplers were common during the past year due to inoperative float switches, pumps, solenoids, sample trap mechanisms and electronic controls. Plumbing leaks, battery failures and freezing also caused frequent maintenance and poor data. The Interagency Sedimentation Laboratory has made numerous changes and improvements on the samplers during the past year and two of the four samplers have been altered by installing new trap mechanisms, air solenoids, tank float switches and electronic controls. These changes have caused delays in completing instrumentation and loss of much important data.

The Chickasha pumping samplers cannot be effectively used at sites where quantities of sand may be pumped through the system because the pump impellers soon fail. H wever, these samplers have proven very reliable at sites where only fine grained sediments are in suspension. The Chickasha sampler is an excellent device for instrumentation of small watersheds and fine grained sediments. Also, screening of the intakes to prevent plugging by flood debris is very important since no back-flushing system is available with the sampler.

The purchase, installation, and maintenance costs for automatic sediment sampling equipment and facilities has been extremely high because of (1) rapidly increasing initial cost of equipment, (2) continuing redesign, (3) need for spare parts when repairs and improvements are being made, (4) need for heated facilities and (5) frequent servicing, adjustment, and repair.

Two gravity samplers for suspended sediments were designed and fabricated at the University of Idaho under the direction of Asst. Prof., Myron Molnau, and one of the units was installed at the Summit Drop-Box Weir. However, the sampler failed frequently during field testing and improvements are in progress. At sites where free overfall exists, the gravity sampler operates without use of a pump and a complicated switching mechanism.

Instrumentation of a 14-ft. by 72-ft. runoff and sediment plot was completed in 1970 on the Nancy Gulch watershed. Runoff and sediment are measured in tanks following each runoff event and the system capacity accommodates one inch of runoff.

Catchments for measurement of bed load at weir sites have been constructed on three watersheds as shown in Table 2. The accumulations of sediment are measured following runoff events and then cleaned for the next event.

b. Sediment yield from January runoff

January 1970 precipitation amounts exceeded previous records for any month at several weather stations in Idaho. Generally, the precipitation occurred on 20 consecutive days from January 9 through 28. Similar mid-winter storms have occurred on the Reynolds Creek Experimental Watershed in six of eight years since records began and caused some degree of flooding. Comparative data on precipitation and peak flow are shown in Table 3 for the major mid-winter storm events. Usually, the rain is accompanied by warm temperatures and wind which causes rapid melting of the snow on frozen ground. However, the 1970 flood peak occurred on January 27th after 19 consecutive days of warm temperatures and alternating rain and snow which thoroughly thawed and saturated the soil.

TABLE 3.--Precipitation and peak flow for mid-winter storm events, Reynolds Creek Experimental Watershed.

Year	Storm Period	Peak Flow 1/	Precipitation at Selected Stations 2/		
			R.G. 076459 3/	R.G. 155407 4/	R.G. 176407 5/
		(C.F.S.)	(INCHES)	(INCHES)	(INCHES)
1963	Jan. 28-Feb. 3	2330	2.06	2.60	3.37
1964	December	3800	5.37	10.19	10.58
1965	January	1100	3.21	6.55	7.27
1967	January	266	1.97	5.79	9.49
1968	February	327	1.00	3.92	3.80
1969	January	900	3.69	8.14	9.03
1970	January	730	2.96	9.14	9.52

1/ Outlet Weir, drainage area of 90 sq. miles

2/ Unshielded gages

3/ Raingage elevation 3915 ft.

4/ Raingage elevation 5410 ft.

5/ Raingage elevation 6800 ft.

Sediment yield per unit area was greatest at the lower elevation watersheds as a result of January storm runoff because the deeper snow at higher elevations absorbed most of the rain. Sediment data from three representative stations at various elevations are summarized in Table 4. Storm characteristics, runoff, and sediment yield for the January 1970 event were very similar to the event of January 1969, as shown in Figure 5. On the basis of nearly ten years of record, mid-winter runoff events of near-flood magnitude occur about three years out of four. The usual combination of warm temperatures, wind, rain, snowmelt, and frozen soil have caused the major floods of record with associated high sediment losses. The January 1970 event appears somewhat typical of mid-winter events common to inland areas of Northwestern U.S. although of greater-than-normal magnitude.

TABLE 4.--Summary of runoff and suspended sediment from selected watersheds, 1970.

Watershed and No.	Drainage Area (Acres)	Runoff January (Inches)	Runoff March-June (Inches)	Suspended Sediment Yield January (Tons/acre)	Suspended Sediment Yield March-June (Tons/acre)
Reynolds Mt. East, 166076	100	0.38	10.77	0	0.218
Reynolds Cr. Tollgate 116083	[illegible]	1.22	7.63	0.117	0.409
Macks Cr. at Weir, 046084	7,846	1.01	0.95	0.465	0.054

c. Sediment yield from spring snowmelt runoff

The water content of the snowpack at higher elevations of the Reynolds Creek Experimental Watershed was greater than normal at the beginning of the spring snowmelt season; however, January storms caused melting of much of the snowpack below 5,500 feet elevation. Figure 3 shows the graphs of temperature, runoff, and suspended sediment for the snowmelt seasons of 1969 and 1970. Typically, the major portion of the seasonal sediment yield is associated with peak flow during periods of highest temperature. Table 4 above contains a summary of data on runoff and sediment yield for 1970 at selected stations. Sediment concentrations are extremely low during periods of low flow and do not contribute significantly to the total annual sediment yield amounts.

d. Runoff and erosion plots

A 14-ft. by 72-ft. plot in the Nancy Gulch Watershed was instrumented for measurement of runoff and sediment from natural events. An 8-inch high metal border, collector, tanks, splitter, and FW-1 recorder have been installed for measurement of runoff and sediment from this typical range site. Also, about 20 other plots have been staked at five other sites which represent a wide range of elevation, slope, cover, and soil conditions. The completed plot instrumentation is designed to catch one inch of runoff from the plot and to be pumped and cleaned following each runoff event.

e. Cooperative sedimentation research

Cooperative sedimentation and hydrology research between the Northwest Hydrology Research Center and the Water Resources Research Institute, University of Idaho, Moscow, Idaho, led to the development and fabrication of two gravity-flow suspended sediment samplers for use on a watershed near Moscow, Idaho (Thompson Watershed), and on the Reynolds Creek Watershed.

However, no runoff events have occurred at these stations since installation of the samplers. The 1970 annual report to the Agricultural Research Service by Myron Molnau and D. J. Davis contains data on precipitation, runoff, sediment yield, temperature, radiation, humidity, wind, and evaporation for the Thompson Watershed or nearby stations. During 1970 precipitation was about 30 inches, runoff about 5 inches and suspended sediment approximately 0.044 tons per acre. The report also shows a schematic of the gravity sediment sampler and explains the sampler mechanism and controls.

Comments, Interpretations, and Future Plans:

1. Overland Flow Hydraulic Parameter Study

An overland flow plane is a very important component of a total watershed system. Furthermore, much of the sediment yield from rangeland watersheds may originate from surfaces that could be classified as overland flow planes. Therefore, one emphasis of this sedimentation study has been and will continue to be an analysis of overland flow.

The synthetic laminar-flow resistance parameter data that was obtained from the sectional optimization was used in conjunction with a dimensional analysis and a least-squares analysis to yield predictive resistance parameter relationships. As a result, the following power equations relate the resistance parameter to the precipitation number P (precipitation rate divided by the product of unit discharge and downstream depth) during rainfall and to the Weber number W (the product of unit discharge, downstream velocity, and fluid mass density divided by surface tension) after rainfall:

$$K = 8.95\ P^{0.1431}$$

and

$$K = 15.64\ W^{0.1666}$$

The predictive power equations were tested by including them in the numerical solution of the mathematical model. Resulting predicted hydrographs compared closely to the observed hydrographs, as shown in Figure 3. The exponents of the power equations are small in magnitude (reflecting a small slope for the regression lines), thus supporting a hypothesis that two carefully selected constant values of the resistance parameter are adequate to reproduce the laboratory hydrographs. This hypothesis is supported by the results shown in Figures 2 and 4. The value of the resistance parameter that is chosen for the rainfall period must be larger in magnitude than the value chosen for the recession period, as indicated in Table 1 and Figures 2 and 4. The fact that two constant values may be used satisfactorily suggests that the hydrographs are fairly insensitive to changes in the precipitation number and the Weber number.

In another study a stochastic streamflow model was used to sequentially generate synthetic records for the Cascade River at Marblemount, Washington. Statistics of generated flow sequences compared closely to the respective

statistics of the 36-year historic flow sequence. Gumbel method estimates of the 100-year maximum and minimum flows also compared reasonably to those obtained by sequential generation.

Future plans for further overland flow analysis under this research outline include a field evaluation of the mathematical model. Field plots, 14 ft. by 72 ft., have been selected at various locations on the Reynolds Creek Experimental Watershed. Borders and water and sediment measuring devices will be installed during 1971 and 1972. Artificial rainfall will be applied to the plots with a portable sprinkler system. Runoff hydrographs will be measured in conjunction with sediment yields in an attempt to relate the overland flow parameters to sediment yields. The runoff hydrographs will also be used to test further the mathematical model of overland flow.

Other future plans include developing a new research outline during 1971 for further study of surface runoff. Further analysis of the overland flow model will be conducted using previously published data by other authors. This analysis will provide an unbiased check on Schreiber's model, since it was developed from a limited set of laboratory data. This analysis is a necessary prerequisite to the plot-runoff field testing program. The overland flow model will then be expanded to include a channel network and several overland flow planes. The new surface runoff mathematical model will be tested by runoff data obtained from the laboratory (Palouse Rain Tower and other published data) and the field (Reynolds Creek Experimental Watershed and other published data). A comparison of results obtained by the proposed surface runoff model will also be made to results obtained by the instantaneous unit hydrograph approach.

Publications completed and in preparation since last year's report are the following:

Schreiber, D. L. 1970. Overland flow simulation by a nonlinear distributed parameter model. Ph.D. thesis. College of Engineering, Washington State University, Pullman, Washington, June.

Schreiber, D. L., and Bender, D. L. Sequential generation of annual streamflow. SWC approval granted September 1970 for publication in the Transactions of the ASAE. Submitted to ASAE November 1970.

Schreiber, D. L., and Bender, D. L. Obtaining overland flow resistance by optimization. SWC approval requested January 1971 for publication in the Journal of the Hydraulics Division, ASCE.

2. Sediment yield studies

There is a definite need for a greater number of sediment measuring stations in Idaho, Eastern Oregon and Eastern Washington if erosion, stream sediments and reservoir sedimentation are to be measured, understood and controlled. Only a few of the numerous stream gaging stations are instrumented for sediment sampling although serious erosion and sedimentation problems are evident in many places. Therefore, a network of sediment measuring stations are needed to supplement long term data from stream-gaging stations.

The accurate measurement of total sediment from plots, watersheds, and large drainage basins requires the use of the best available sampling devices

and techniques. Therefore, efforts must be continued to develop and improve automatic suspended sediment samplers for field use.

Experience at the Northwest Watershed Research Center has proven (1) that procurement, installation and maintenance of automatic sediment samplers are very expensive at remote sites when operated to monitor winter floods during freezing weather, (2) that less expensive Chickasha and Interagency P.S. 67 pumping samplers are useful only at certain sites and have limited reliability, and (3) that improved sampling devices and techniques are needed under the difficult field conditions encountered.

Above average winter precipitation and snow accumulation in 1970 caused runoff and sediment yield similar to that of several other years of record and is, probably, representative of conditions to be expected in about three out of four years. Soil loss from major Reynolds Creek Watersheds approaches one inch in 100 years on the basis of limited data.

With continued support and cooperation of the Bureau of Land Management, measurement and analysis of sedimentation on plots, from source areas and from streams will continue, improve and increase. Also, all available data is being processed and analyzed for publication.

The gravity suspended sediment samplers at Moscow, Idaho (Thompson Watershed) and at the Reynolds Creek Watershed will be thoroughly field tested during natural runoff events to determine the reliability of the equipment. The usefulness of these samplers for runoff-sediment plots and small watershed studies will be investigated. A paper and slides describing the gravity sampler were presented at the 25th Annual Meeting of the Pacific Northwest Region of the American Society of Agricultural Engineers, October 7-9, 1970, as noted:

Johnson, C. W., and Molnau, Myron.
A gravity sediment sampler for drop-box weirs. 25th Annual Meeting of Am. Soc. of Agr. Engineers, Oct. 7-9, 1970, Bozeman, Montana.

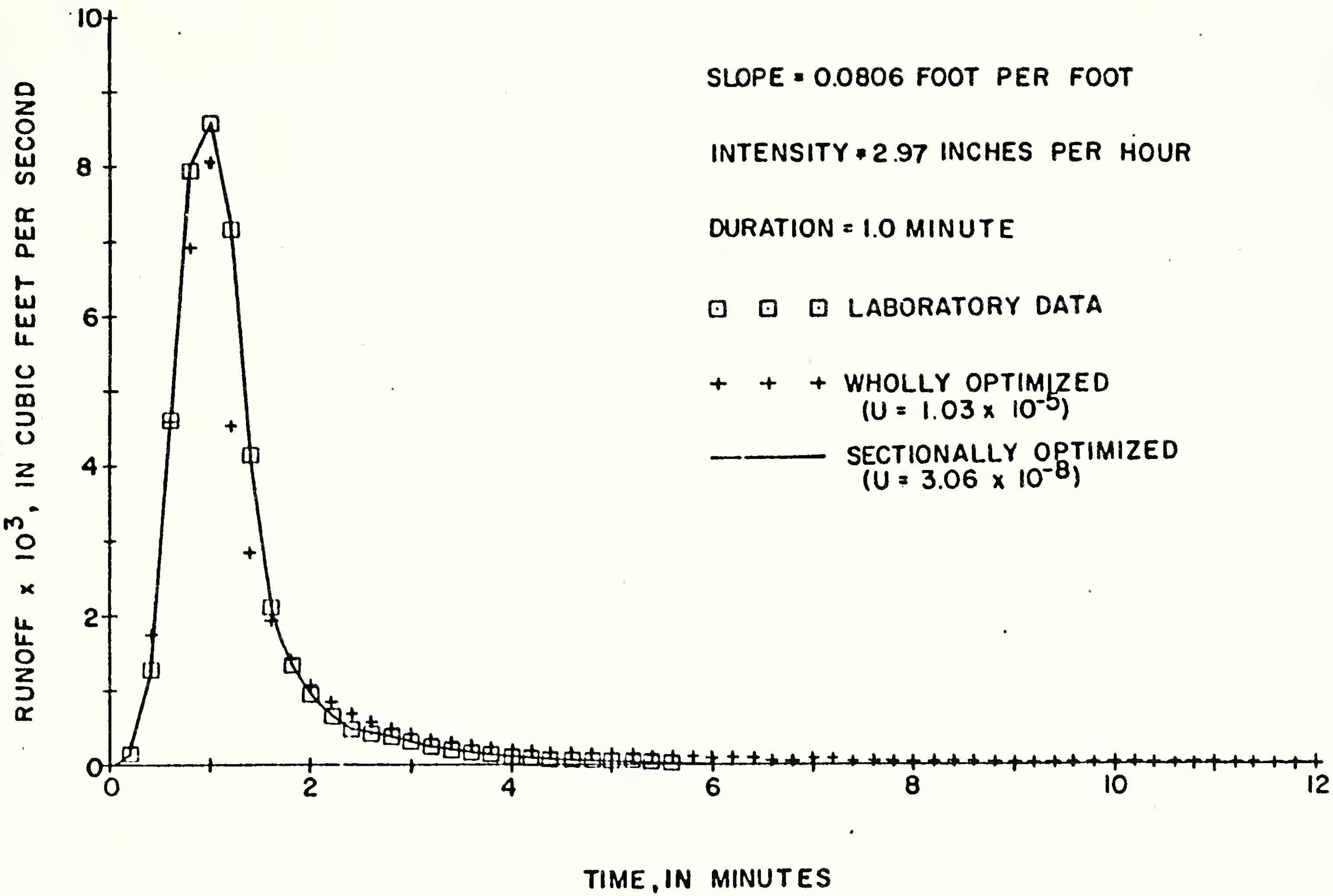

Figure 1. Observed and optimized hydrographs for test 27.

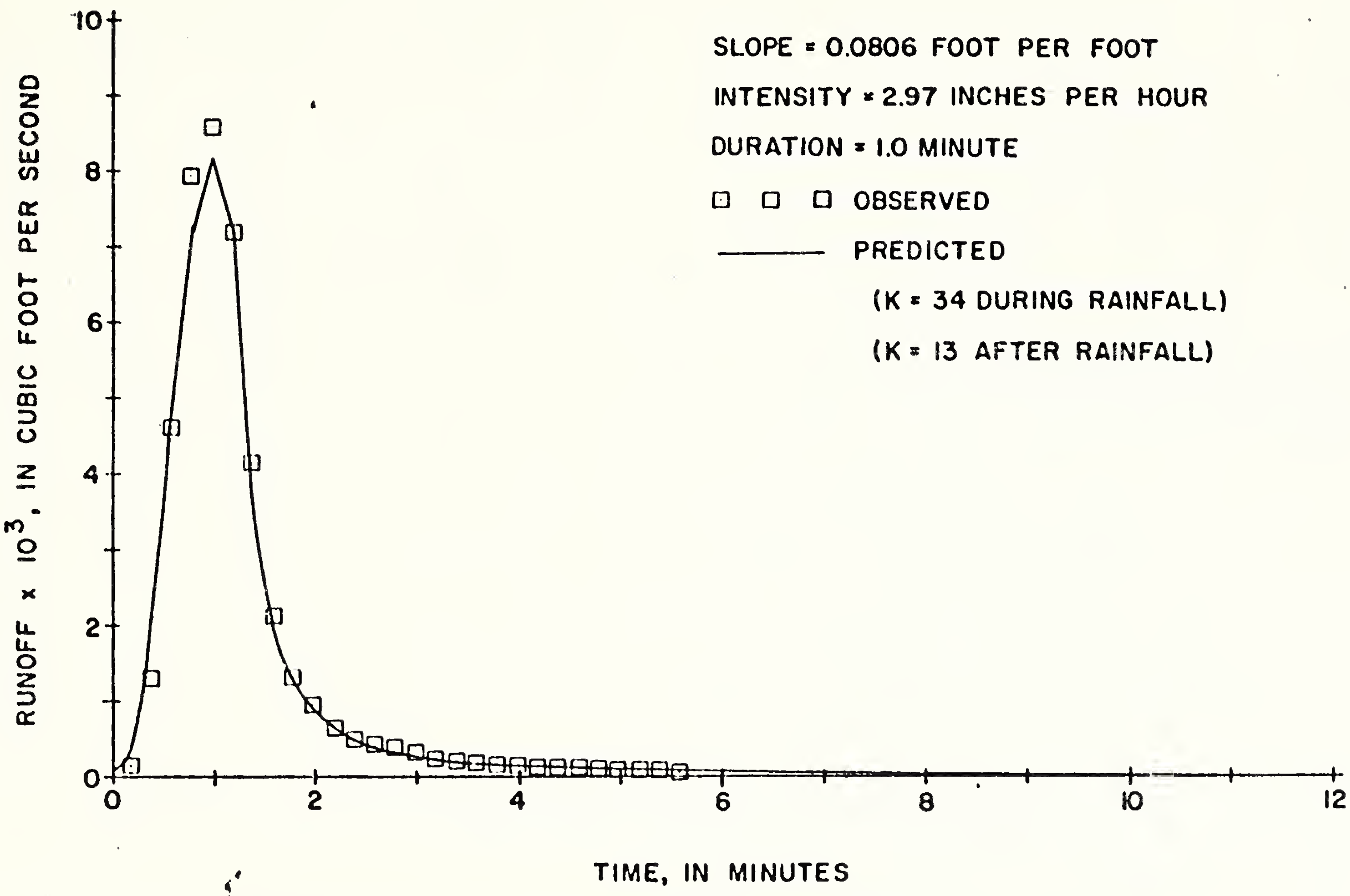

Figure 2. Observed and two-piece optimized hydrographs for test 27.

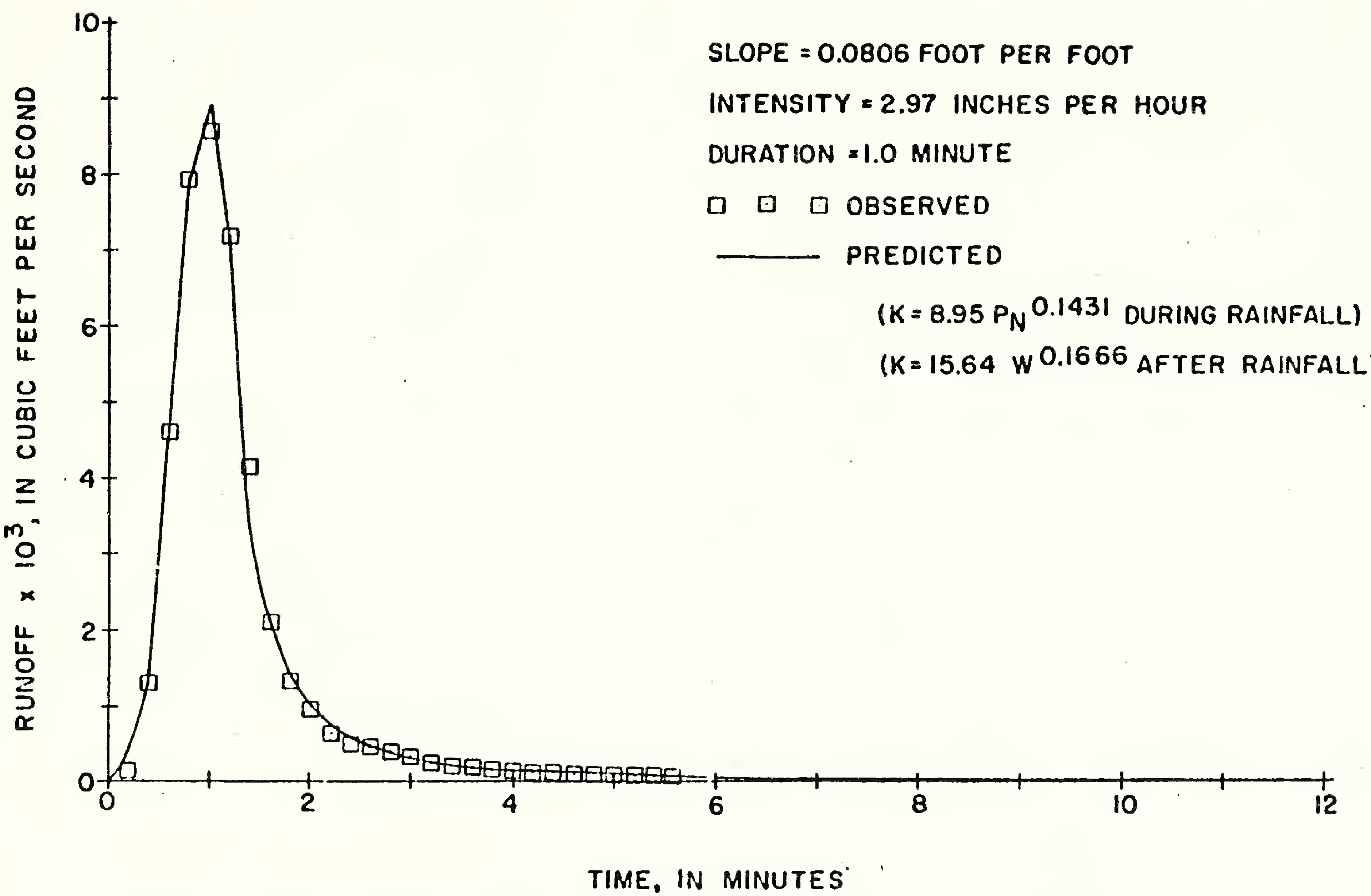

Figure 3. Observed and predicted hydrographs (based on power equations for K) for Test 27.

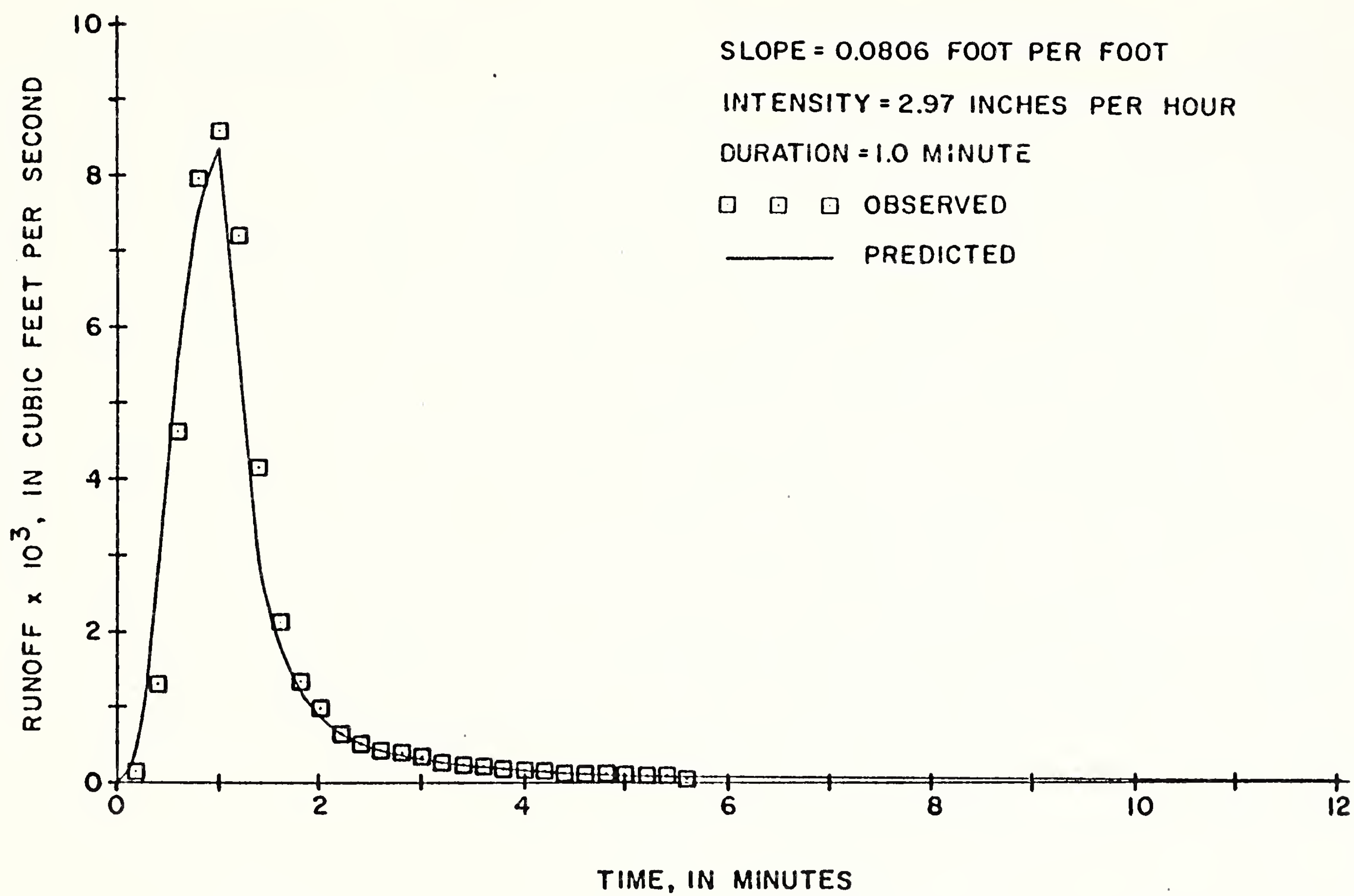

Figure 4. Observed and predicted hydrographs (based on K = 24 during rainfall and K = 14 after rainfall) for test 27.

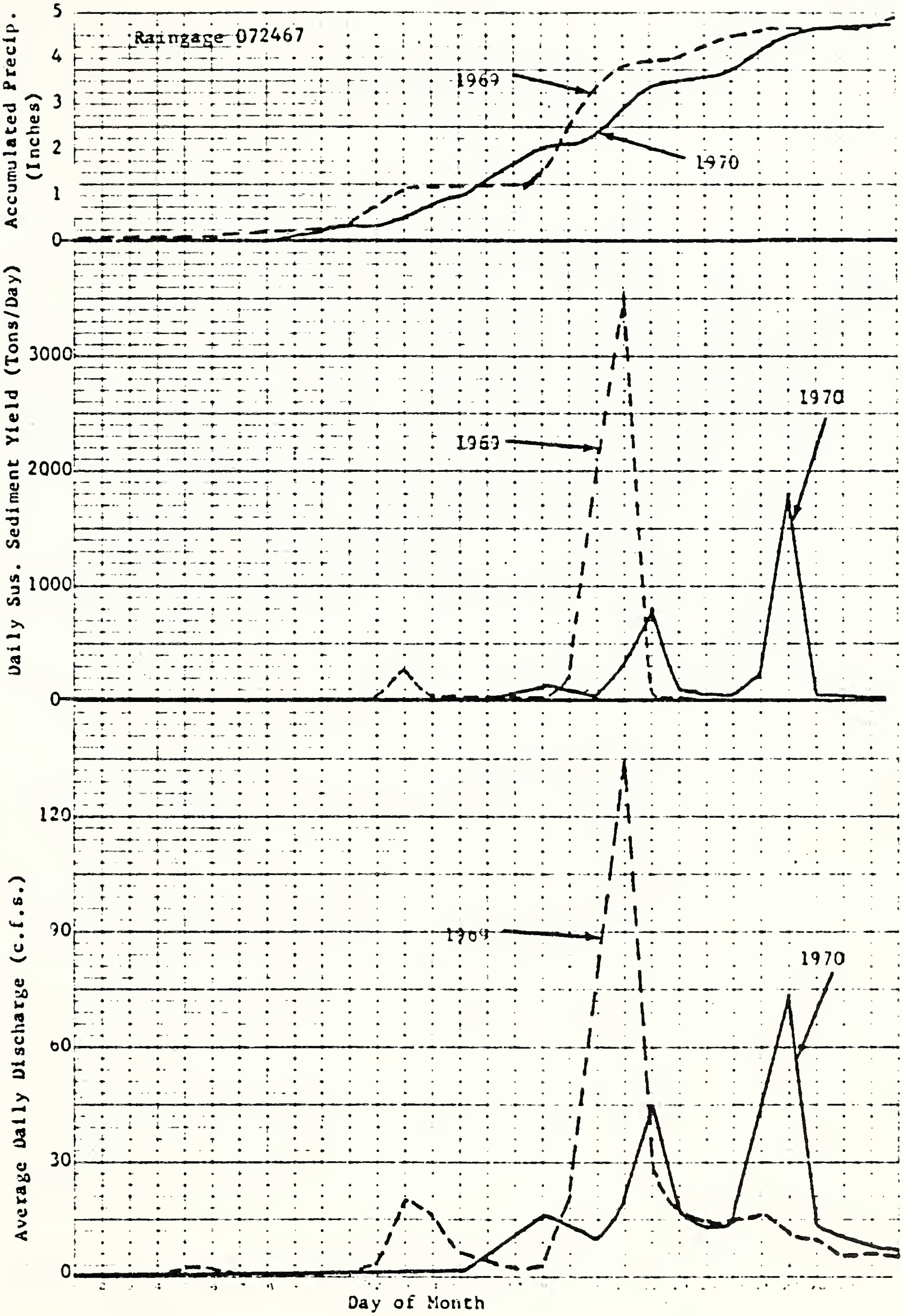

Figure 5. Precipitation, runoff, and sediment yield (suspended) for Macks Creek Watershed, January, 1970.

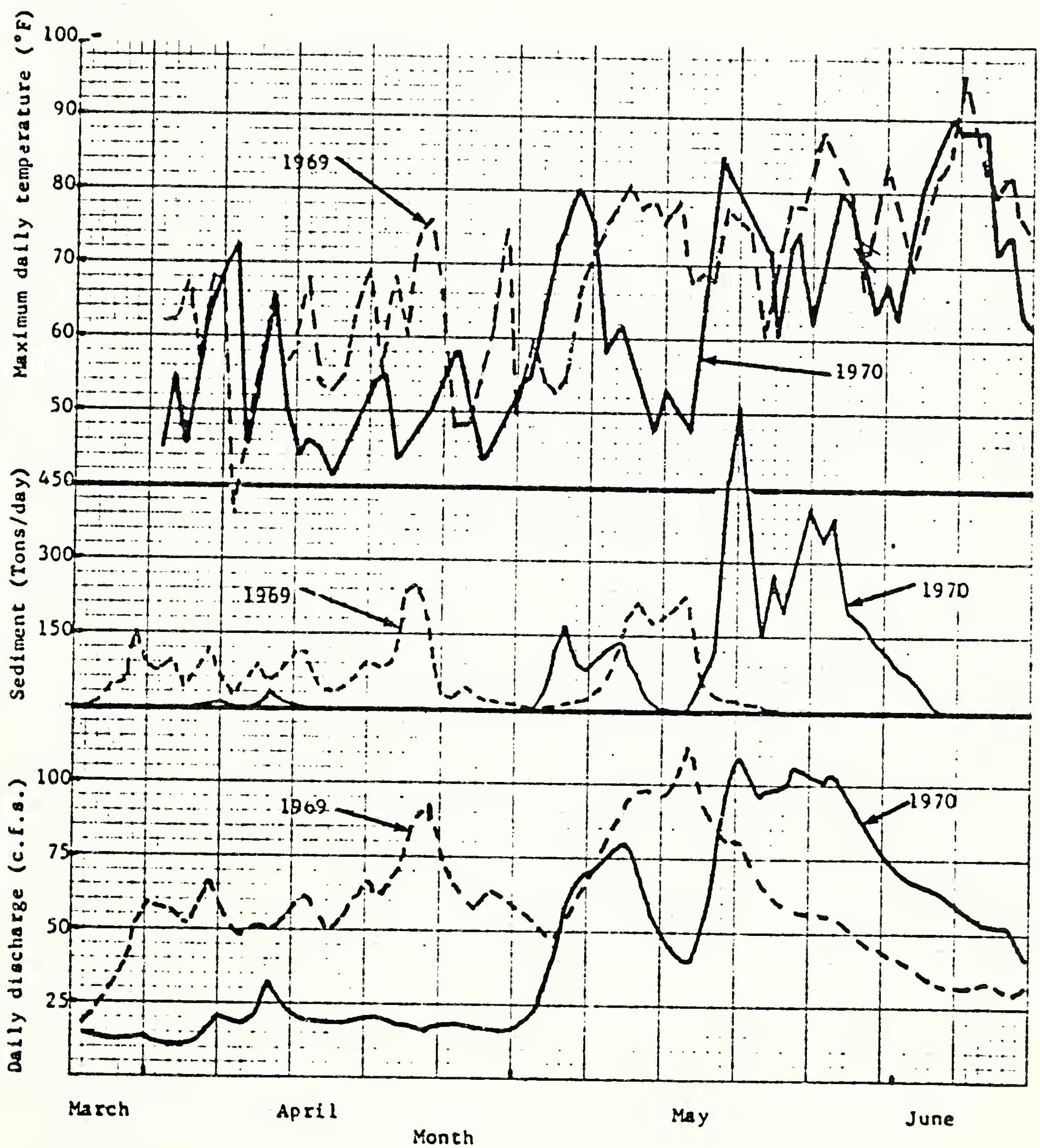

Figure 6. Temperature, runoff and suspended sediment yield, Reynolds Creek at Tollgate, 1969 and 1970. (Temperature from Reynolds Weather Station)

SUMMATION OF IMPORTANT FINDINGS

SWC-011-fBo-1 Influence of climatic, biologic, and physical factors on rangeland watershed hydrology

Data collected during a rain-on-snow event demonstrated that the snowpack can store a considerable amount of water. Of the 1.82 inches of precipitation that fell as rain (measured by an unshielded gage), only 1.44 inches of water came out the bottom of the snowpack. Therefore, at least 0.38 inch of rainwater was stored within the 11-inch snowpack, with an initial water equivalent of 1.28 inches. (Ida-Bo-100.1)

Computed precipitation, using data from shielded and unshielded gages, for the water year 1969-70 in the Reynolds Creek Experimental Watershed, exceeded the precipitation caught by unshielded gages by about 1 inch where the total precipitation caught by the unshielded gage was 10 inches, but exceeded the catch by nearly 14 inches at higher elevations where the total catch was about 31 inches. The unshielded gage catch was only about 69 percent of the computed precipitation at the higher elevations where the greater percentage of precipitation occurred as snow and where wind speeds are greatest. (Ida-Bo-102.1)

A developed mathematical model for computing actual precipitation from shielded and unshielded gage data, independent of wind and type of precipitation, utilizes wind functions for the ratios of catch by shielded and unshielded gages to actual precipitation. Data for the direct computation of actual precipitation are not available, except in the Reynolds Creek Watershed, since precipitation is universally observed by use of only unshielded or shielded gages. Coefficients have been derived by use of the mathematical model, and data on catch by shielded and unshielded gages, temperature, and wind to convert catches by either unshielded or shielded gages to estimates of actual precipitation as a function of wind and temperature. The ratio for unshielded gage catch to actual precipitation for temperatures of 23° to 32°F. is 0.71 for a wind of 10 m.p.h. and is 0.36 for a wind of 30 m.p.h. The coefficients derived makes it possible to convert precipitation measured by ordinary gages to estimates of actual precipitation by use of wind and temperature data. (Ida-Bo-102.6)

Data collected during a long period of high continuous snowmelt further demonstrates the differential response of the 12 ft. butyl pillow and the universal gage to decreases in water equivalent of the snowpack. Under high melt conditions the water equivalent measurement as made by the universal gage clearly exhibits distinct diurnal changes as compared to only continuous linear decreases for the 12 ft. butyl pillow

measurement. This difference in response appears to be associated with differential settling of the snowpack on the flexible surface of the 12 ft. butyl pillow and the temporary mounding of water on its surface. (Ida-Bo-102.7)

Studies of channel roughness in laboratory flumes and natural channels have shown the complex interaction of: (1) shape, spacing, and size of bed roughness elements; (2) geometry and slope of the channel; and (3) flow velocity and turbulence. Parameters to describe various bed element spacing, size distribution, intensity and effective height have been useful in comparing random and regular flume roughness patterns to show that maximum flow resistance for a specified intensity occurs with random spacing of elements. Also, narrow channels have greater flow resistance than wide channels with equal bed roughness. (Ida-Bo-104.1)

Removal of a dense sagebrush growth by grubbing and by spraying with 2-4-5-T resulted in a threefold increase in herbage yield compared with an untreated control area after two growing seasons with no grazing. Measured soil moisture depletion was greater and snow accumulation less where brush had been removed. Studies at other sites with different brush cover, annual precipitation, soils and grazing use are in progress to fully verify the favorable forage yield increases indicated on the first study site and to verify any differences in soil moisture depletion. (Ida-Bo-105.4)

A mathematical model of a steady-state, two-dimensional flow system resulting from snowmelt infiltration on a watershed slope has been partially verified by 1970 field data obtained from the north slope of Upper Sheep Creek Watershed W-17, a sub-basin of the Reynolds Creek Experimental Watershed W-1. Analysis of the field data indicate that steady-state conditions were not fully achieved during the snowmelt period of 1970. The mathematical model does, however, indicate what types of additional observations should be obtained. Limited field data verify to a degree, the indications from mathematical solutions that the saturated hydraulic conductivity of the soils (1) decreases with depth below the ground surface, and (2) decreases upslope from the stream channel for about one-third the distance, then increases sharply at this point, and decreases again upslope until near the top of the slope where it once more increases. (Ida-Bo-105.5)

Mathematical models of transient, partially saturated, one-dimensional vertical and three-dimensional axisymmetric, flow through soils have been developed and partially verified by laboratory data obtained from a soil from the Reynolds Creek Experimental Watershed. A modified Burdine Theory provides a functional relationship for obtaining, from saturation-capillary pressure data, the change of relative hydraulic

conductivity with capillary pressure. Reasonably good agreement is attained between observed conductivity-pressure data and the results predicted by the modified Burdine Theory. Solution results from the two mathematical models indicate that boundary effects on circular infiltrometers significantly alter the flow pattern, even reducing the saturation at the surface centerline appreciably over that which would exist for the same application rate over an infinite area. (Ida-Bo-105.6)

A rainfall simulator-gamma probe-infiltrometer with a combination of capillary needle sizes, air and water pressure, is capable of duplicating the median drop sizes of natural rainfall up to intensities of 4 inches/hour. The control of drop sizes and intensities also make it possible to produce a desired rainfall energy even though terminal velocities are not reached. (Ida-Bo-105.6)

Laboratory tests of a new, commercially available two-probe (gamma) density gauge utilizing a tracking, differential pulse height discriminator for temperatures ranging from 37° to 80°F, indicates that density readings (both means and variances) are not significantly different. The probable error in the measurement of soil moisture on a large laboratory sample over a saturation range of 55 to 85 percent was 0.63 percent. (Ida-Bo-105.6)

Estimates of evapotranspiration by the Bowen ratio method and by energy balance-combination equations are in agreement for irrigated alfalfa, but the Bowen ratio estimates are considerably smaller for semiarid sagebrush rangelands. The apparent difficulty in using the Bowen ratio method in semiarid environments lies in the assumption of equality in the transfer coefficient of heat and water vapor and in obtaining reliable measurements of very small vapor pressure gradients. The popular energy balance-combination equations for computing evapotranspiration that require humidity data in addition to surface temperature and radiation data that are required in the basic energy balance equation are of limited use since their results are redundant. Their only purpose is in the formulation of an equation for estimating potential evaporation, where for a saturated surface, the inclusion of air humidity eliminates the need for surface temperature data. (Ida-Bo-106.1)

Water balance computation for watersheds in southwestern Idaho during the water year 1969-70 indicate that nearly all precipitation was lost to evapotranspiration in areas with less than 15 inches of precipitation while 67 percent was lost in the 20- to 40-inch precipitation zone. The water yield was 10 inches from the 20- to 40-inch precipitation zone. (Ida-Bo-106.1)

For a semiarid low sagebrush site, the surface albedo was observed to be relatively constant at 13 percent in early June. The net radiation was estimated with reasonable accuracy as a

linear function of incoming solar radiation. A close correlation was also found between the soil heat flux and net radiation. A regression of evapotranspiration on net radiatio yielded a simple correlation of 0.77. (Ida-Bo-106.1)

SWC-012-fBo-2 Ground water in relation to management of rangeland watersheds in the Northwest.

A systematic change was noted in percent volume soil water in the saturated zone at constant depths of measurement under an irrigated field. The cause may be due to instrument error as a result of temperature sensitivity. Soil water information, including corrected soil water values for the saturated zone, and changes in the piezometric water levels, were used to assess specific yield and evapotranspiration to compute total water loss. The loss values computed to date average 23 percent, which is reasonable for loam soils such as these as mentioned in the literature. (Ida-Bo-103.3)

From a correlation analysis of water level elevation versus ionic ratio from ground-water samples in a basalt aquifer flow system, it was found that silica (SiO_2) decreases downstream in the flow system. A negative correlation (-0.996) for total dissolved solids to silica (TDS/SiO_2) versus water level elevation, shows that TDS increases downstream in the flow system. Analyses to date indicate that these characteristics are predictable and can be used with confidence for water quality mapping purposes in the area of study. (Ida-Bo-103.4)

SWC-011-fBo-3 Effect of runoff, precipitation, climate, soil, vegetation, land use, and land form on sediment yield.

A mathematical model developed to simulate and predict overland flow hydrographs was verified by laboratory data. Parameter optimization provided a set of representative, synthetic resistance parameter values. The synthetic data and a dimensional analysis yielded predictive resistance parameter relationships. Resulting predicted hydrographs compared closely to the observed hydrographs. Satisfactory results are also obtained with a constant resistance parameter value during rainfall and a constant of lesser magnitude during recession. As indicated by the results of this study, sediment yield from overland flow planes is probably initiated during rainfall periods, since turbulence effects are greater. (Ida-Bo-107.1)

Two years of experience with three Interagency P.S. 67 pumping samplers have resulted in numerous failures involving almost every mechanical and electronic part of the sampler systems. Therefore, continued development and improvement of automatic

suspended sediment sampling equipment is very important. Also, a network of suspended sediment sampling stations is urgently needed in Idaho, Nevada and Eastern Oregon to compliment long term runoff records throughout the area. (Ida-Bo-107.1)

Sediment yield from Southwest Idaho watersheds above 6000 feet elevation is mainly contributed during the spring snowmelt season. In contrast, watersheds from 4000 to 6000 feet elevation contribute the greatest sediment during mid-winter runoff events which occur when soils are frozen or nearly saturated. However, extremely dry or wet years may cause a change from the somewhat normal pattern. Delineation of major sediment source areas under the extremely variable topography, soil and cover conditions found in the Reynolds Creek Watershed is very difficult without runoff-sediment plots to define the factors which greatly influence erosion and sediment production from specific sites. (Ida-Bo-107.1)

LIST OF PUBLICATIONS

SWC-011-fBo-1 Influence of climatic, biologic, and physical factors on rangeland watershed hydrology.

Published:

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SUMMARY TABLE OF STATUS OF RESEARCH OUTLINES

		Status Code
SWC-011-fBo-1	Influence of climatic, biologic, and physical factors on rangeland watershed hydrology.	
Ida-Bo-100.1	-- Snow accumulation and melt on study areas	B
Ida-Bo-102.1	-- Precipitation characteristics of a northern, mountainous, semiarid watershed	B
Ida-Bo-102.6	-- Evaluation of precipitation gage performance	D
Ida-Bo-102.7	-- Evaluation of pressure pillows, and hydraulic weighing and catchment devices for snow and precipitation measurements	D
Ida-Bo-104.1	-- Resistance coefficients for steep-rough channels	D
Ida-Bo-105.4	-- Evaluation of cover production, herbage yield, and soil conditions for different levels of management	B
Ida-Bo-105.5	-- Field testing and evaluating mathematical models of a two-dimensional, infiltration flow system resulting from snowmelt	B
Ida-Bo-105.6	-- Developing, testing, and evaluating an analytical infiltration model	B
Ida-Bo-106.1	-- Natural evaporation from sage-brush rangelands, alfalfa, and stock ponds in a semiarid environment	B
SWC-012-fBo-2	Ground water in relation to management of rangeland watersheds in the Northwest.	
Ida-Bo-103.3	-- Ground-water flow system under an irrigated field	D
Ida-Bo-103.4	-- Geochemistry of ground-water flow systems	B

SWC-014-fBo-3	Effect of runoff, precipitation, climate, soil, vegetation, land use, and land form on sediment yield.	Status Code
Ida-Bo-107.1 -- Sediment yield from rangeland watersheds		B

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